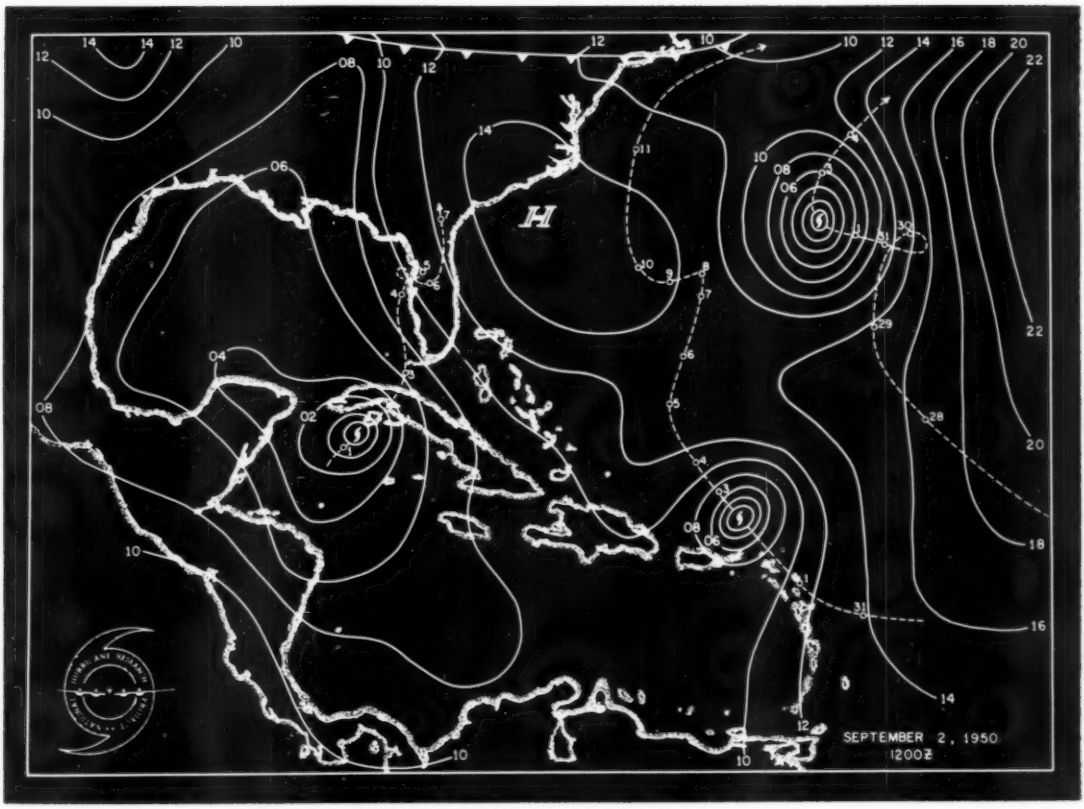
Weatherwise



Volume 14, Number 3 June 1961

"SOME PEOPLE ARE WEATHERWISE BUT MOST ARE OTHERWISE"—BENJAMIN FRANKLIN

WEATHERWISE

THE MAGAZINE ABOUT WEATHER

DAVID M. LUDLUM, *Editor* HENRY W. BULKLEY, *Associate Editor*

Second Technical Conference on Hurricanes

Miami Beach, Florida—27–30 June 1961

27 June	9:00 a.m.	General Session on Tropical Meteorology
	2:00 p.m.	Radar Analysis of Tropical Cyclones
	7:30 p.m.	Visit to National Hurricane Center & Reception
28 June	9:00 a.m.	Observing-Tracking Systems and Facilities
	2:00 p.m.	Storm Surge
29 June	9:00 a.m.	Formation of Hurricanes
	1:45 p.m.	Energy Cycles and Models
	6:30 p.m.	Reception and Banquet, Barcelona Hotel
30 June	9:00 a.m.	Circulation and Energy Processes in the Storm Core
	2:00 p.m.	Prediction of Hurricane Movement

The Conference is under the joint sponsorship of the American Meteorological Society and the Greater Miami Branch, AMS. Mr. Harry F. Hawkins, Jr., National Hurricane Center, Miami, is chairman of the program committee. Technical sessions will be held at the Barcelona Hotel, 4343 Collins Avenue, Miami Beach.

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Front Cover: The classic surface chart for 0730E, 2 September 1950, shows three hurricanes simultaneously dominating the Western Atlantic area —Hurricane Charlie northeast of Bermuda, Hurricane Dog northeast of Puerto Rico, and Hurricane Easy (the Cedar Keys hurricane) south of Cuba. Isobaric labels are in tens and units of millibars with the hundreds omitted.

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FIG. 1. Home of the National Hurricane Center, The Aviation Building, Miami, Florida—1. 5th Floor, North Wing, Hurricane Forecast Center—DMO. 2. 5th Floor, South Wing, NHRP Headquarters. 3. Offices of Research Flight Facility. 4. 7th Floor, Joint Facilities—Library—Conference Room—Drafting—Film Reading—Radar Maintenance—Research. 5. WSR-57 Radome. 6. Navy Fleet Weather Facility. 7. Project Mercury Support Group. 8. American Airmotive Facilities at Miami International Airport where research planes are housed and maintained. 9. Weather Bureau Airport Station, Miami. All of these establishments contribute in greater or lesser degree to the National Hurricane Center.

The National Hurricane Center

HARRY F. HAWKINS, JR., *Acting Director, National Hurricane Research Project,*
LEONARD G. PARDUE, JR., *Meteorologist, District Meteorological Office,*
and CARL M. REBER, *Chief, Research Flight Facility*

IN April 1959 the National Hurricane Research Project and the newly organized Research Flight Facility moved from West Palm Beach to Miami and took up quarters adjacent to the Hurricane Forecast Center in the Aviation Building. These units comprise the National Hurricane Center designed to accelerate progress in hurricane research and to speed the application of this research to hurricane forecasting. It is the purpose of this article to describe the new complex and to discuss its objectives, capabilities, and functions as these relate to the hurricane problem.

DEVELOPMENT AND STATUS OF THE HURRICANE FORECASTING CENTER

From earliest history, residents of the Tropics have sought to predict hurricanes. Over the years, as a body of experience and tradition was acquired, many empirical rules were developed, some fairly reliable, some of occasional value, and some worthless. Concurrent with the great surge of interest in meteorology during the middle and latter parts of the nineteenth century, hurricane forecasting gradually acquired some semblance of formal standing in the more enlightened communities of the Tropics. The

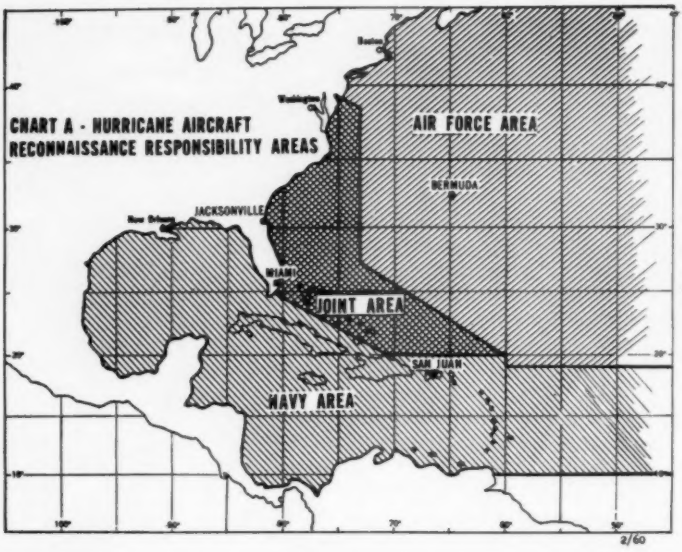


FIG. 2. Areas for which the indicated Service has prime responsibility for hurricane and tropical storm reconnaissance by aircraft.

forecasting task more often than not fell to the nearest or most interested missionary or representative of a learned institution. Marked improvement had to wait a more complete collection of synoptic information, made possible through the advance of telecommunications.

The first forecasting service, as an arm of the Federal Government, was inaugurated by the Signal Corps of the U. S. Army in 1870. Forecasting of coastal storms was an important function of the service from the beginning. The first hurricane warning of which we have definite record was issued on 23 August 1873.

Following tentative operation from locations in the Tropics, responsibility for hurricane warning, by this time a function of the civilian Weather Bureau, was centered in Washington in 1903. Earlier, during the Spanish-American War, President McKinley is said to have told Weather Bureau Chief Willis L. Moore that he feared a hurricane more than he feared enemy action.

In 1935 the Hurricane Warning Service was established with major forecasting centers in New Orleans, Jacksonville, and San Juan, in addition to Washington. The hurricane teletypewriter circuit, essential for the prompt exchange of information between coastal points, was opened that year with twelve stations strung around the coast from Jacksonville to Brownsville. Gradual growth of this circuit, particularly during the war years, increased its coverage to about fifty stations; in addition a secondary hurricane circuit was gradually built, stretching from Miami to Boston via East Coast forecast centers and vulnerable cities.

Wartime requirements led to the removal of the Jacksonville center to Miami in 1943. Here it has remained, partly because of the strategic location and partly because of the inherent value of maintaining close contact with the people to be served and the unparalleled communication and information channels available. Liaison requirements with the military led to the designation of the Miami office as the official coordinating center between Weather Bureau hurricane forecast centers in the Gulf-Caribbean-Atlantic sector, on the one hand, and Air Force and Navy reconnaissance and forecast units on the other.

Radio silence imposed by wartime necessity virtually shut off information from merchant and other surface vessels in 1942. After a number of exploratory hurricane flights in 1943, aerial reconnaissance became an invaluable aid to analysis and forecasting in 1944 and subsequent years. Reconnaissance techniques and observing equipment aboard hurricane reconnaissance aircraft have been improved from year to year until this type of operation, while still regarded as a challenge

to an aircrew, is considered almost routine in nature.

Regular aircraft tracking and reconnaissance of hurricanes are carried out by Air Force and Navy units. The map (fig. 2) shows the division of areas of responsibility. When a hurricane, tropical storm, or suspicious area is known or suspected to be generating, the Service having responsibility in that area is contacted and a reconnaissance flight requested. The Navy Airborne Early Warning Squadron Four (the Hurricane Hunters) operates out of Puerto Rico while the U. S. Air Force Detachment No. 3, 55th Reconnaissance Squadron is deployed from Bermuda. Coordination of the day's flight(s), establishment of succeeding nights' and days' capabilities, agreement as to altitudes, flight tracks, and a myriad of other operational details must be decided on by the Air Force Hurricane Liaison Officer, the Commander of Navy Fleet Weather Facility, and the Weather Bureau forecaster on duty. When a shortage of trained air crews or ready aircraft develops in one or the other service, mutual cooperation prevents a situation from becoming critical.

The objectives of these flights include the location of the center ("obtain a fix") of the weather disturbance whether it be a raging hurricane or an area of squally weather, measuring the intensity of such disturbances; i.e., the strength and extent of the winds surrounding it, and the minimum pressure, heights of clouds, etc. Successive fixes at 6-hour intervals or more often are necessary for accurate tracking of the center.

The importance of these flights cannot be overestimated. One of the necessary ironies of present warning and communication facilities is that at the present time most ship captains are alert and take advantage of hurricane advisories which concern their routes. As a result, fewer ship reports are available today from the areas of hurricane activity than were available 30 years ago. In this sense at least, the issuance of effective warnings has tended to reduce the data necessary to help provide accurate warnings. Consequently, greater and greater reliance has been placed on aircraft observations.

Within the last year, however, a new battery of instruments has come into the hands of the Hurricane Forecasting Service which lessens the total reliance on aircraft as the hurricane approaches the coast. A new chain of WSR-57 radars lines the coast from Brownsville, Texas, to New England. A full-blown hurricane approaching within 200 miles of the coastline is now kept under constant radar surveillance. The WSR-57's are supplemented with reports from military establishments and by radars operated by universities. As a result, a hurricane may be under continuous surveillance of more than one radar at the same time. Equally important

FIG. 3. The WB-3 Super Constellation built to Navy specifications and used in tropical storm and hurricane reconnaissance. The large dome below contains the APS-20E 10 centimeter weather radar, the upper dome contains a vertical scan radar which permits vertical analysis of the radar targets. These planes are characterized by extremely long range, and regularly perform 20 to 22 hour flights.

FIG. 4. The WB-50 or modified B-50 bomber of World War II used by the Air Force reconnaissance squadron based at Kindley AFB, Bermuda. These planes carry a three-centimeter radar and are equipped with accurate navigational devices which permit continuous determination of latitude and longitude plus practically instantaneous values of flight level winds.

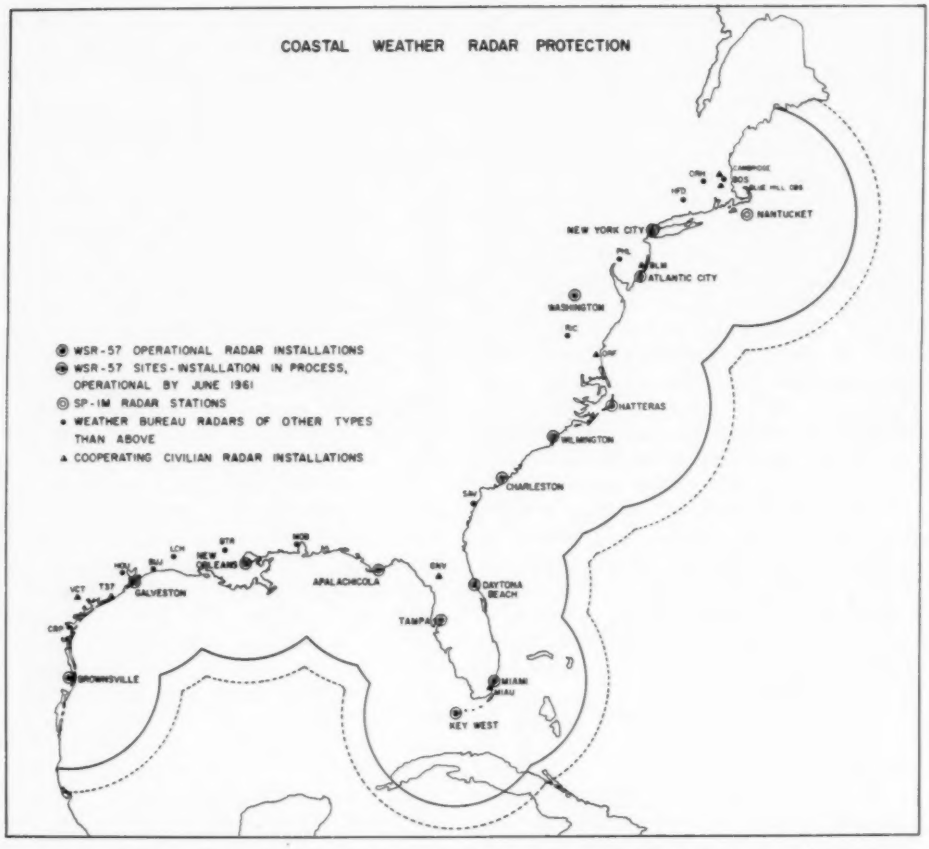


FIG. 5. The above diagram illustrates the defense net against undetected invasion by hurricane or other severe meteorological disturbance. The dashed (- - -) arcs show the extreme range of WSR-57—250 nautical miles. The solid(—) arcs show the coastal protection at ranges of 200 miles, within which any severe disturbance such as the hurricane should be clearly visible and subject to continuous tracking. The sites indicated here are augmented by Air Defense Command radars which, in hurricane emergencies, are partially manned by Bureau observers and thus supplement the protection indicated above.

is the benefit resulting from a hurricane's being tracked by a down-wind radar station as it passes out of range of an up-wind station. Reports from these radar sites are teletyped to the Hurricane Center on an hourly basis. The effectiveness of this network was more than amply demonstrated by the information and protection it afforded during Hurricane Donna of September 1960.

The drawback associated with radar coverage is the lack of quantitative information such as strength and extent of the dangerous winds and the central pressure data which cannot yet be obtained from radar observations. Research is currently underway to find out if information of this type can be obtained through radar techniques. Consequently, the reconnaissance aircraft and their radioed reports are often the only source of reliable data about very important items which tell a forecaster the size, strength, and depth of a hurricane.

In hurricane situations additional data are available from many voluntary observers who have been supplied with instruments by the Weather Bureau. The Weather Amateur Reporting Network (WARN), composed mostly of amateur radio operators, some of whom furnish their own instruments, was one of the earlier networks to secure formal recognition. Operating in Florida, it now comprises about fifty stations. Of greater geographical extent, the Cooperative Hurricane Reporting Network (CHURN) was established in 1957.

These two networks and others of local importance, plus Coast Guard, municipal, public utility, and privately operated stations, make their observations available and result in coastal observation points at twenty-five mile intervals, or less.

A Navy Fleet Weather Facility, having the primary responsibility of preparing specialized forecasts designed specifically for Naval requirements, is located adjacent to the Miami Hurricane Forecasting Center of the Weather Bureau. This proximity permits close consultation between the two groups of specialists.

The Air Force Hurricane Liaison Office coordinates the reconnaissance "plan of the day" with the detachment at Kindley Air Force Base, Bermuda. The proper Air Force authorities at Bermuda are thus kept fully advised as to the foreseeable hurricane reconnaissance requirements they may be asked to meet. They, in turn, take whatever action is possible to provide air crews and ready aircraft. In addition, the AFHLO Officer will either plan or take part in planning the flight track to be flown at altitudes requested to ensure that operational limitations of aircraft and crew are not exceeded, while at the same time the meteorological information of greatest value to the forecaster is obtained.

Further requirements on the AFHLO office are related to the hurricane forecasts and warnings. This material is tailored for Air Force use by the officer on duty and is dispatched over Air Force communication nets to the appropriate installations. Here again close touch is maintained with developing situations and the thinking behind the forecast so that interpretation and application to specific installations can be made.

Also lodged in the forecast quarters is the Project Mercury Support Group, a specialized team of forecasters and analysts supplying weather forecasts and briefings for the "man-in-space" operation at Cape Canaveral. This location was chosen because of the unequalled facilities for weather-data collection from the areas where the most frequent recoveries are expected; also, specialists with years of experience in these areas are available.

The Weather Bureau is committed to warn all civil interests in the United States and its possessions. As a facet of international cooperation, hurricane warnings are also issued for certain foreign areas. All hurricane warnings do not originate at Miami although as the National Center it is consulted by other hurricane forecast centers having specified areas of responsibility. The centers are: New Orleans, Washington, Boston, and San Juan. Continuity, guidance, and counseling are provided by Miami and the National Meteorological Center at Suitland, Maryland. Actually 75% of hurricane activity occurs within the zone of Miami's responsibility.

Being thus located quite close to so much hurricane activity and at the focal point of communication facilities entering and leaving the southeast, Miami has developed into a major forecast center and has been designated a District Meteorological Office of the Weather Bureau. One of the major problems of this office has been to obtain rapid and efficient dissemination of forecasts and warnings to the public.

It is axiomatic that no forecast or warning is useful until in the hands of those to whom it is directed. All modern means of communication are used for rapid dissemination, including national and regional teletypewriter circuits reaching all Weather Bureau offices and those of the Federal Aviation Agency. An FM radio network regularly serves seven key stations in Florida and has the capability of reaching any broadcasting station in the peninsular portion of the state. It is intended as a prototype for similar operations nationwide.

NATIONAL HURRICANE RESEARCH PROJECT

The National Hurricane Research Project was established at the behest of Congress in late 1955. Its purpose was and still remains the improvement of hurricane forecasting. This objective includes accurate prediction of the inception, intensification, and decay of hurricanes, as well as forecasts of their motions in all their eccentricities. Taken into account are such features as rapid accelerations in forward motion and rapid changes in direction. Prediction of the coastal high water levels induced by the hurricane is an integral part of this assignment.

It was recognized at the outset that sufficient observations did not exist to accomplish these aims in a physically meaningful way or, indeed, even in a satisfactory empirical

fashion. As a result, plans were made to gather new basic data on hurricanes by two means: (1) expansion of the upper-air reporting network in the West Indies into the so-called West Indies Radiosonde Network (WIRN), which now comprises some nine stations, and (2) the instrumentation of suitably stressed aircraft to probe the high-energy core of the hurricane and bring back new detailed information on the variation of meteorological parameters in the hurricane itself. These data are necessary for development of the physical picture needed to describe the mechanisms governing hurricane formation, maintenance, and motion.

In addition, plans were laid to exploit currently available climatological-synoptic data by establishing research forecast positions at the various hurricane forecasting centers. The assignments of these research people were to systematize the hurricane emergency procedures at their stations, to array synoptic data relative to hurricane situations so they could be used on future occasions and, if possible, to derive objective forecasting techniques for their particular areas of responsibility.

For the purpose of gathering the new basic investigation data, a research operations base was established in West Palm Beach, Florida, in 1956. The U. S. Air Force made available two WB-50s and one WB-47 to the Project during the 1956–58 hurricane seasons and provided air crews and facilities for their operation. The planes were heavily instrumented so that detailed meteorological observations could be recorded at a rapid rate. The functions of the Research Operations Base were to plan and stage the missions, reduce and process the data, and take part in the research work. In addition to these activities, experiments were conducted in tropical analysis and forecasting.

This basic arrangement remained in force for the three seasons 1956–1958, at the end of which time the Air Force offered to loan to the Weather Bureau the two WB-50s and the WB-47, so that if further flight activity was necessary the Weather Bureau could continue the program for an additional period with alternative arrangements for operation of the aircraft.

Investigation revealed that maintenance and operations of the WB-50s and WB-47 would be an unrealistic task for a civilian organization since these planes had heretofore been maintained exclusively by the military. In fact, studies revealed that it would be more economical to lease and operate two DC-6s than it would be to operate two WB-50s rent free. Furthermore, since the cost of operating the WB-47 was so great, the Air Force

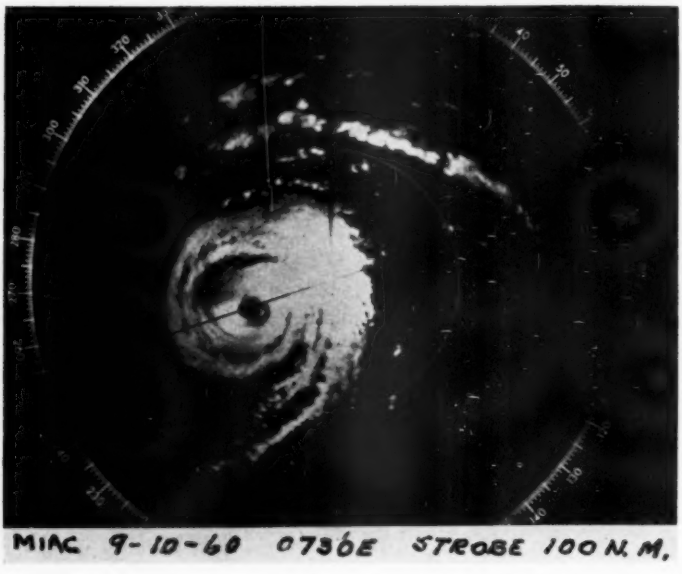


FIG. 6. A radar picture showing the complete structure of hurricane Donna taken by the WSR-57 at the National Hurricane Center on the 10th of September 1960, 0730E. The well marked circle is at a range of 100 miles from Miami (which is at the center of the scope). The well marked line of clouds from north-northwest to north-northeast of the storm (north being upper-most in the picture) is the squall line well out in advance of the hurricane proper. At about 255 degrees is the well marked eye of hurricane Donna surrounded by a solid wall of precipitation. Strong well-marked spiral bands winding into the center plus the almost solid rainshield lying between the eye and Miami make this almost a textbook picture of a model hurricane.

agreed to loan the Weather Bureau a B-57A for the necessary high-altitude reconnaissance. Following this original arrangement, the B-57 has been transferred outright to the Weather Bureau. The instrumentation of these planes was begun in 1959 and after some unforeseeable delays was completed early in 1961. Meantime, the many uses to which the planes were to be put and the unique kind of a unit which it comprises have resulted in the formation of the U. S. Weather Bureau Research Flight Facility. The capabilities and functions of this group are outlined in an adjacent section.

Concomitant with the decision to lease DC-6s, it became apparent that continued operation at West Palm Beach was impossible. Facilities for civilian maintenance of the planes were not available in that locality and a decision as to a future base of operations was required. It was at this time that the possibilities inherent in the unification of these rather diverse elements with the Hurricane Forecast Center, already long established at Miami, began to appear attractive. Consequently, in April 1959 the NHRP moved into expanded Weather Bureau quarters at the Aviation Building in Miami, thus coalescing with the Hurricane Warning Center (also the District Meteorological Office). There were obvious economical benefits to be derived by such a merger. These included the elimination of duplication in communications facilities and of communications charges between the two units which occurred when they were physically separated. Other items of similar nature included the sharing of drafting, duplication, photographic, computer, and other facilities.

More to the point, however, were the somewhat intangible advantages which might accrue in such a merging of capabilities and talents. Since the ultimate goal of the Project is improvement in prediction, it seemed highly desirable that the people working on this problem be in the closest possible touch with those currently on the "firing line" and making predictions with the techniques already at hand. This should ensure that the researcher be well aware of the most pressing problems from the forecasters' point of view while, at the same time, any step forward in research could be, after adequate testing, readily implemented in the forecast procedures.

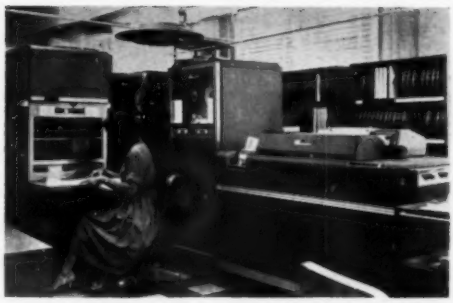


FIG. 7. Computer installation at NHRP. An IBM 650 is used to process the raw meteorological data gathered on research flights and to reduce it to meaningful form for use by scientific investigators. The machine is also used to make mathematical computations which are too laborious to be undertaken by hand calculator.

To these joint advantages should be added a distinctly operational aspect, namely, that the Hurricane Forecast Center had at its early disposal practically all of the synoptic and other reports available in hurricane or potential hurricane situations. Thus, the complete analysis routinely performed at the station would eliminate the necessity of similar analyses being carried out at the Research Operations Base. The pooling of effort and skills in this area should result in more comprehensive and careful analyses and more thorough evaluation of the situation and its potential. This collaboration should make possible more effective deployment of the hurricane research flights and thus allow more meaningful hurricane data to be gathered. Also, in the course of such flights a certain portion of operational hurricane reconnaissance requirements can be fulfilled by the research flights themselves. Experience gathered during the 1960 hurricane season indicated that personal contact between the reconnaissance meteorologists and the forecaster on duty was extremely beneficial and informative.

It is not intended that the full scope of NHRP interests and activities be encompassed in this article. It should, however, be pointed out that in addition to the work being carried on at Miami a sizeable amount of research is pursued through research contracts, consultants, and collaborators at:

University of Chicago
Massachusetts Institute of Technology
Florida State University
University of Miami

Colorado State University
Woods Hole Oceanographic Institution
University of California at Los Angeles
New York University
University of Wisconsin
Travelers Weather Research Center
Meteorological Research Institute of Japan

At all of the above places, contributions are being made to hurricane research and the problems peculiar to meteorology in the Tropics. As results of these efforts become available, they are made known to fellow researchers and operating personnel concerned through the NHRP Preprint Series. The Preprint Series is not a formal publication but a method of rapid communication between a researcher and those concerned with his work.

Of great benefit to the National Hurricane Center and its hurricane operations are the visits these highly-specialized professionals pay to NHRP during the hurricane season, which fortunately almost coincide with academic vacations. The form which their contributions to the Center may take are varied but enlightening. A resume of last season's activities may serve as an example.

Professor N. E. LaSeur of Florida State University, and associate director of the NHRP, conducted and took part in the Center's joint map discussions, flight planning for hurricane research and reconnaissance, did research on Hurricane Cleo of 1958, and taught (together with Mr. Landers of FSU) a course in physical climatology.

Professor Herbert Riehl of Colorado State University, with Mr. Gray, and Mr. Pike assisting, developed a more objective set of criteria for hurricane genesis and introduced these items into a modified map discussion. Experiments in using satellite radiation data were carried on and sea surface temperature summaries were prepared. Professor Riehl also presented his course in tropical meteorology to some 15 students.

Professor Jerome Spar of New York University spent six weeks at NHRP in a consulting capacity and contributed special low-level wind analyses to the discussions.

Messrs. Neil Frank and Edward Zipser, graduate students from Florida State University, took part in specialized map analysis for the Center and carried out research on hurricane data gathered by the research aircraft.

Among other shorter-term visitors were:

Dr. T. Fujita, University of Chicago
Dr. A. Kasahara, University of Chicago
Mr. Robert Jones University of Chicago
Mr. Keith Veigas, Travelers Weather Research Center

The many and diverse contributions these visitors have made to both operational and research problems have met with uniformly warm recognition; their cooperation ensures that maximum competence is available in any specific area where advice or assistance is needed.

THE RESEARCH FLIGHT FACILITY

As indicated in the previous section, the Research Flight Facility has only recently developed into a separate entity and was previously an integral part of NHRP. Now that planes are available on a year-round basis, they have been deployed in problems in severe storms, clear air turbulence, and the like; thus a more coherent operation is possible under the new arrangements.

Data from the research aircraft to support the hurricane research effort are obtained primarily from the specially instrumented research aircraft of the RFF. These aircraft are dispatched into areas at times best calculated to insure the collection of research data on selected meteorological conditions. Home base for the aircraft is Miami, Florida, but frequent staging operations are made from installations at Bermuda, San Juan, and other points to extend the range of operations.

The major purpose of these specially instrumented aircraft and supporting crews is the measurement of selected conditions for research purposes. Their availability and actual use in normal reconnaissance operation are limited to meeting requirements which may not always be covered readily by normal Air Force or Navy reconnaissance.

The complex measuring and data recording systems aboard each of the three aircraft—two DC-6A's and one military type B-57A—are maintained by a team of Weather Bureau technicians. These technicians also fly on the DC-6A aircraft to operate the equipment. However, since the B-57 has space for only

TABLE 1

PARAMETERS RECORDED ABOARD RESEARCH AIRCRAFT

Sub-System	Parameter	Instrument	Remarks
Meteorological parameters	Temperature	Vortex thermometer	No dynamic corrections required
	Temperature	Rosemount probe	High response rate
	Humidity	Infra-red hygrometer	
	Wind direction	Doppler radar system	
	Wind speed	Doppler radar system	
	Liquid water content	Paper-tape type	Electrical conduction principle
	Liquid water content	Hot-wire type	Electrical resistance principle
	Icing	Heated probe	On-off type instrument derives rate indirectly
	Absolute altitude	Radio altimeter	Modified Canadian Mk V.
	D-value	Hypsometer/radio altimeter	Modified Canadian Mk V.
	Absolute pressure	Pressure transducer	
	Differential pressure	Pressure transducer	To derive accurate air speed for calibration computations
Flight condition	Pitch and roll	Gyro system	
	Indicated air speed	Pitot-static system	
	True air speed	Pitot-static system plus temp. sensor.	
	Pressure altitude	Pitot-static system	
	Drift angle	Doppler system	
	Heading	N-1 compass system	
	Latitude & longitude	Doppler system	
Radar systems	Search radar	APS-20E (DC-6A only)	
	Safety radar	WP-101 on DC-6A	
	Search & safety radar	RDR-1D (B-57 only)	
Photographic system	Radar photography	O-15 cameras	
	Cloud photography	Time-lapse cameras	
	Photo-panel	Time-lapse cameras	

one crew member in addition to the pilot, a flight meteorologist flies in the aircraft to operate the equipment and direct the research data collection. Each DC-6A aircraft carries up to two flight meteorologists to perform in-flight analyses and direct the research effort. The flight meteorologists perform data review and otherwise prepare the information for scientific use when they are not flying. Crews for the aircraft are specially trained in the requirements for flying in order to obtain the most useful research data. An example of the utilization of the research aircraft may be drawn from the record on Hurricane Donna, in which almost 100 flying hours were expended in obtaining detailed measurements.

Instrumentation aboard the aircraft is aimed at obtaining the highest possible accuracy under operational conditions, and to utilize automatic data recording. A description of the total instrumentation system, divided into subsystems, is contained in Table 1.

The primary data-recording is accomplished on magnetic tape. This record, when run through a suitable computer, provides a tabulation of each parameter. Instrumental calibrations and basic computations can be accomplished at the same time the print-out is made. Data samples are usually at the rate of one complete sample each second, but rates up to one-tenth second are practicable for selected purposes. A secondary data recording of the more critical parameters is provided by photographing an instrument panel display of dial indicators.

The heart of the primary data-recording system is the digital data-handling equipment built to Weather Bureau specifications. These data-handling systems, which in some respects

FIG. 8. The eye of hurricane Cleo (1958), taken on one of the NHRP research flights. Aircraft altitude was 15,000 feet; the undercast below tops at 6,000 to 10,000 feet with the sea beneath visible through breaks. The wall cloud rises to a height of about 48,000 feet, and the eye diameter was approximately 35 nautical miles. Inside the eye, flying conditions were quite smooth but the wall cloud was as usual an area of considerable turbulence, very heavy rain, with winds over 100 miles per hour.

may be likened to digital computers, receive information from the various sensors, or other information outputs, encoded in binary form. The logic circuitry of the data-handling system is such that incoming information from each source is stored momentarily while a master sample time control system allows the information to pass through in sequence to complete the sample record. All this is accomplished in relatively few micro-seconds, following which the machine resets itself to record the next complete data sample. Master time control is provided by a crystal oscillator operating at radio frequencies which are "divided-down" to get the several different frequencies necessary to control the circuitry. This master time system also provides the real time indication by which all data recorded aboard the aircraft are identified. Built-in checks and monitor features warn the operator when the data-handling system is making mistakes and provision is made for rapid servicing in flight.

Vital to the research flying are the several radars installed on the planes. In the DC-6A aircraft, Navy-type APS-20E radars permit searching out the storm areas of interest, and the nose-installed airline type radar assists the pilots in avoiding the hard cores that present undue hazards to flight. Aboard the B-57A is a standard airline-type radar that serves both for safety of flight and, with a photographed repeater scope, records the presentations on film.

Research data from aircraft are of little, if any, practical value unless it is known where, as well as when, the information was obtained. For most flights, navigation records for research purposes are provided by a Doppler Navigation System which, with

associated circuitry, makes it possible to read out flight level wind direction and wind speed directly. The accuracy of the latitude and longitude values from these systems is often better than one per cent of total distance traveled. For selected research purposes, it is necessary to determine with the greatest possible accuracy the location of the aircraft in true coordinates and then translate this position information to virtual latitude and longitude. This adjustment relates the position of each observation to the storm system being investigated.

Cloud photography, used to study individual conditions and also to correlate occurrences, is accomplished by time-lapse cameras. On the DC-6A aircraft such photographs are taken from the nose section of the aircraft and also toward the side. On the B-57A, photography is directly ahead.

Collectively, the research aircraft now working to support the efforts of the National Hurricane Research Project probably constitute the most advanced meteorological research aircraft in general use today.

Instrumentation of the aircraft to their present state would not have been possible without the wholehearted cooperation of the Navy and Air Force who, realizing the value of this program, contributed much of the specialized equipment such as radars, navigation systems, and special probes.

Additional installations are scheduled for completion this summer, including a specially designed cross-section radar for scanning in the vertical. Also planned for installation are special vertical-motion probes which will make it possible to determine the vertical motions of the atmosphere and to measure the smaller-scale eddy circulations which are known to exist within the broadscale flow. Another installation involves the mounting of cloud seeding equipment aboard the DC-6's so that limited experiments on hurricane modification can be undertaken while the storm is too far out at sea to affect land installations.

Obviously, most of the RFF summer activities are directed solely to research purposes. Nevertheless, many operational values accrue to the National Hurricane Center through proximity to the RFF base. Communication time and difficulties do not allow for transmission of all data the flight meteorologist would like to convey to the forecaster. Debriefings after flights are very useful. In the case of the B-57, only a very limited amount

FIG. 9. One of the DC-6/A aircraft used by the Research Flight Facility in hurricane reconnaissance. The radome on the bottom contains the APS-20E weather surveillance radar as well as other antennae for Doppler Navigation and radar determination of altitude. The small dome immediately forward contains the time-lapse 16mm movie camera. Vortex and Rosemount temperature probes are immediately above window number 2 with the liquid water content meters atop the aircraft. Infrared hygrometer port is on the port side and the special pitot-static system is off the picture but on a boom extending forward from the right wing. Conventional airline radar is mounted in the nose of the aircraft.

FIG. 10. The B-57/A which has been transferred by the Air Force to the Weather Bureau. This is the high altitude probe used by the Research Flight Facility, and is instrumented in an analogous fashion to the DC-6's except that the large AFS-20E antennae cannot be carried on this type aircraft. Reconnaissance at altitudes of 40,000 to 45,000 feet are routine with this facility.

of data, if any, can be radioed back to base because of the many other duties of the pilot and flight meteorologist. Debriefing in this case usually includes getting the necessary observations for evaluation of meteorological conditions over the hurricane at high levels.

The researchers of NHRP must actively participate in the flight planning and also take part in the flying if meaningful data for their projects are to be forthcoming. The joint efforts of these two teams are also necessary in getting the maximum information out of any recorded set of observations. Thus proximity and cooperative effort are essential for maximum effectiveness.

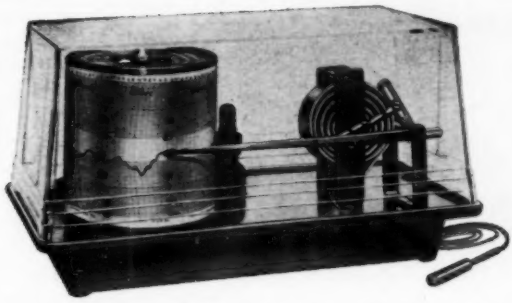
SUMMARY

In the scale of such undertakings, the National Hurricane Center is still quite young, but certain advantages of the new organization can already be cited: renewed academic interest through meteorology courses given at the Center; additional material, prepared for the forecaster's consideration and presented and evaluated by skilled researchers, to be distinguished from the mere addition of another chart to an already lengthy array; material assistance to the forecast staff in critical situations through the assignment of research personnel to operational details; and benefits to research personnel from this direct exposure to operational demands.

It is reasonable to conclude that the pooling of capabilities and talents in forecasting, research, and observational technique at the Center will yield additional benefits that will be reflected in accelerated progress in hurricane research and in the improvement of hurricane forecasting.

FIG. 11. Joint Map discussion at the National Hurricane Center, summer season, 1960. The various groups involved in the National Hurricane Center complex contribute specially prepared material for the joint consideration of the forecasters and research personnel in attendance.

Low Cost Thermographs



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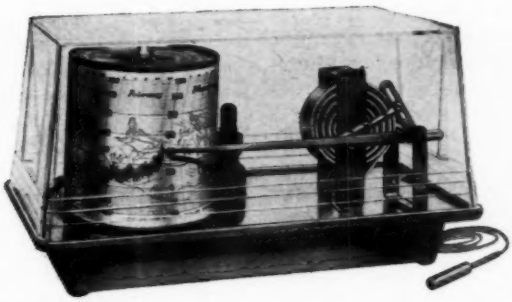

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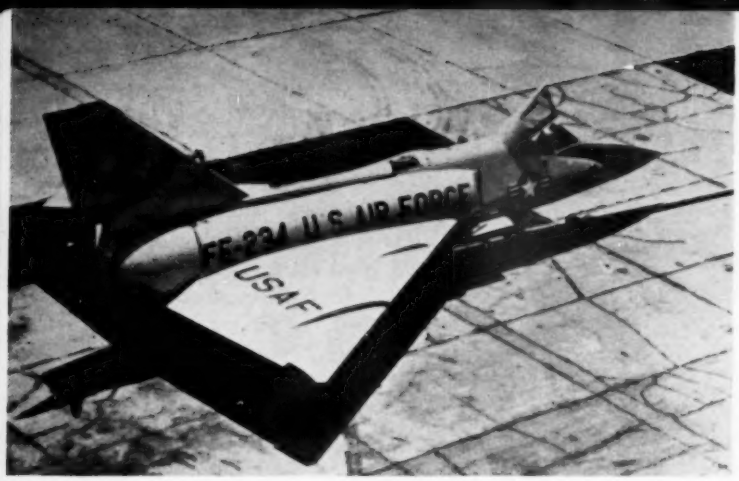


The F-106, a supersonic fighter plane which is being used by NASA and WADD to study thunderstorm turbulence.

The 1961 National Severe Storms Project

DANSY T. WILLIAMS, *U. S. Weather Bureau, Kansas City, Missouri*

THE National Severe Storms Project (NSSP), re-named from last year's National Severe Local Storms Research Project (NSLSRP), began field operations on March 15th this year when operating personnel began moving to the staging area at Oklahoma City, Oklahoma. Greatest concentration of effort was made during the severe storm months of April and May, when 10 groups with a dozen or more aircraft were probing severe thunderstorms and the environments that spawn them.

Groups and agencies collaborating this year include the National Aeronautics and Space Agency (NASA); the Federal Aviation Authority (FAA); the U. S. Air Force's Wright Air Development Division (WADD), Geophysical Research Directorate (GRD), Air Defense Command (ADC), Tactical Air Command (TAC), and Air Weather Service (AWS); the U. S. Navy's Weather Research Facility at Norfolk, Virginia; the U. S. Army Signal Corps; and the U. S. Weather Bureau's Research Flight Facility (RFF). Director of NSSP is C. F. Van Thullenar. The Chief Scientist is Dr. Chester W. Newton. Support by the Weather Bureau Central Office is provided through Robert H. Simpson, Deputy Director of the Office of Meteorological Research (Severe Storms).

Objectives of the 1961 project include studies of the large-scale storm environments, the structure and life cycle of severe storm systems and their components, interactions between storms and their environments, factors that determine storm intensity, the water and energy budgets of severe storms, and the effect of severe storms on the control and design structure of aircraft.

Aircraft to be used include a B-26, a B-57, and two DC-6's of the RFF; a B-66 and B-47 of WADD; an F-106 of NASA and WADD; a B-47, C-130, and U-2 of GRD; an A-3D of the U. S. Navy; and a B-66 of TAC. Some of the aircraft will be used during the entire season. Others will be available for part time duty. Many of the aircraft have capabilities for complete in-flight recording of meteorological elements. Others have certain special capabilities such as high level photography (U-2), turbulence measurements (F-106 and WADD's B-66), and dropsonde (TAC's B-66). An aircraft of the type used for penetration of storm cells is shown in figure 1.

Vectoring of project aircraft will be accomplished by utilizing the specially modified WSR-57 radar at Will Rogers Field, Oklahoma City. This will permit detailed sectioning of individual storm cells by penetration aircraft, as shown in Figure 2. The WSR-57 and other radars in the Oklahoma City vicinity will also be used as coordinated units to

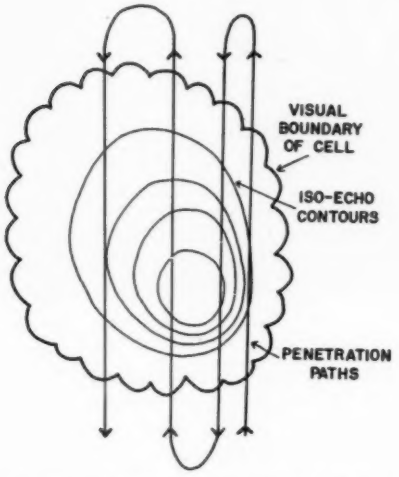
make quantitative measurements of precipitation and motion fields in severe storms.

The Severe Local Storms Research Network of surface stations in Kansas, Oklahoma, and Texas, is being used again this year, but with an additional network at reduced spacing within the main network to the southwest of Oklahoma City. Stations of the inner network are spaced at 10–15 mile intervals to provide greater detail of surface features.

Soundings are being provided by regular stations of the U. S. Weather Bureau and the U. S. Army Signal Corps and regular and mobile stations of the Air Weather Service. Sounding coverage is increased by scheduling them serially at one to one-and-one-half hour intervals. A compact coverage is attained in the operating area by the Weather Bureau station at Oklahoma City, the Signal Corps station at Fort Sill, and Air Weather Service stations at Altus and Ardmore, Oklahoma.

Stereophotography from ground sites will be employed by GRD to ascertain the formation, motions, and dissipation of storm systems.

NSSP, which had a modest beginning as the Tornado Research Airplane Project in 1955, is now engaged in one of the largest field research programs ever conceived for the study of a geophysical phenomenon.



Flight pattern in which a penetration aircraft sections a storm cell with respect to the iso-echo contours of the WSR-57 radar.

Book Review

ATLANTIC HURRICANES

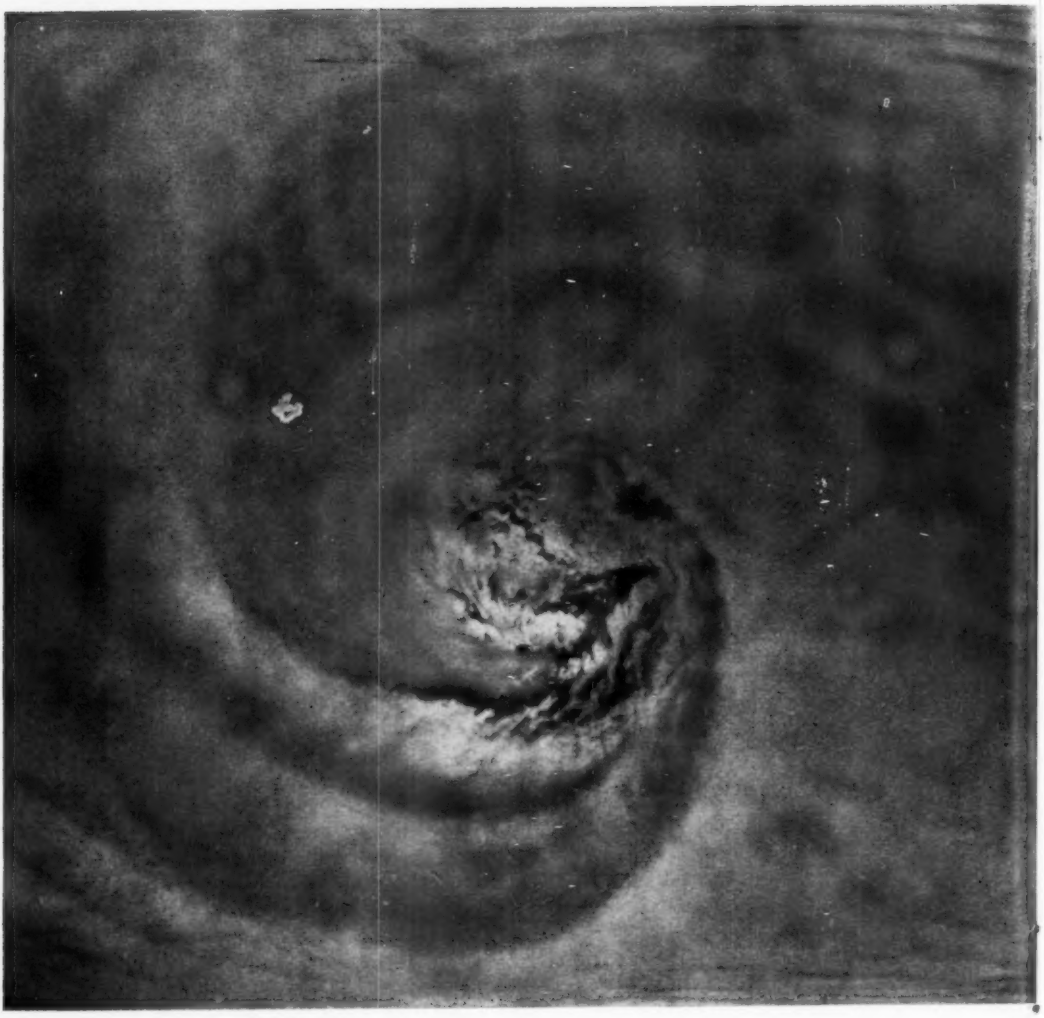
Atlantic Hurricanes. GORDON E. DUNN AND BANNER I. MILLER. Louisiana State University Press, Baton Rouge, Louisiana, 1960. 326 p. 87 figs., 31 tables, 116 refs. $10.00.

For almost 20 years, Ivan Ray Tannehill's book *Hurricanes* was the standard treatise on West Indian tropical storms, going through nine editions between 1938 and 1956. The enormous strides in hurricane reconnaissance by elaborately equipped airplanes and tracking by radar, not to mention the millions of dollars spent in research, analysis, observation, warnings, etc. during the past four years or so, are bound to produce results which should be brought into the formal literature.

With the death of Mr. Tannehill in 1959, the lot of bringing this material to students and the public in a systematic form fell to Gordon Dunn, the leading hurricane expert of the U. S. Weather Bureau for the past decade or more. This long-awaited book gives the latest (up to late 1958) information and data resulting from the research at the National Hurricane Center at Miami, and at other centers in the U. S. and Caribbean, and data from the ocean areas, all in systematic and readable style with graphs, charts, tables, maps, photos, schematic diagrams, etc.

The book opens with dramatic eye-witness accounts (by trained observers) of recent disastrous hurricanes, background information as to terms, girls' names, etc. This is followed by a chapter on tropical weather and circulation; one on hurricane climatology (classification, source regions, frequency, seasonal variation, long period variations); hurricane characteristics (wind, pressure, dimensions, duration, vertical structure and the eye); hurricane swells and surges, tornadoes, lightning and rains; energy sources, budget and modification; formation; warning system of the USWB; location and tracking by ship, aircraft, radar and satellite (TIROS I, April 1960: photo of typhoon, brief description included); forecasting techniques (climatology, continuity, steering, numerical forecasting, Riehl-Haggard system, etc.); intensification and dissipation; destructive forces, prepara-

(*Continued on page 125*)



Superior Photographic Reconnaissance of Tropical Cyclones

ROBERT D. FLETCHER, JAMES R. SMITH, ROBERT C. BUNDGAARD,
Air Weather Service, U. S. Air Force

DURING the period 1956–60, the Air Weather Service of the U. S. Air Force participated in a reconnaissance program of high-level atmospheric research, together with the National Aeronautics and Space Administration. One of its areas of investigation involved detailed observation of typhoons from U-2 aircraft. From the photographic records, the cloud sequences provide an analysis in short-time increments of less than one minute to various intervals up to several hours and cover the development of a number of tropical vortexes over successive days. These analyses qualify the validity of various vortex models hitherto generally assumed in studies of tropical cyclones.

We shall present three photographic series of Typhoon Ida on 25 September 1958. They briefly illustrate certain morphologic and dynamic characteristics of the tropical cyclones reconnoitered by the 3rd Weather Reconnaissance Squadron Provisional, located at Atugusi, Japan. These have been digested from a forthcoming monograph to be published by the American Meteorological Society.

Typhoon Ida originated 200 miles west of Guam on 20 September. By midnight of the 27th its eye was over Tokyo International Airport. It then swept on over the northern islands into the ocean south of the Kuriles.

A total precipitation of 16 inches fell in the Tokyo area, a record for the Japanese Weather Service there. Damage in Tokyo alone totaled almost $3 million. Throughout Japan, Ida left 888 persons dead, 556,000 persons homeless, and 211,000 acres of farmland and rice paddies flooded.

Typhoon Ida had maximum surface winds of 240 knots, with an average of 145 knots. The maximum diameter of its eye was 40 nautical miles. The average radius of 100-knot winds extended 130 nautical miles. At the 700mb level (approximately 10,000 ft.) the maximum eye temperature reached 29.8°C/85.5°F. Within the eye at the same elevation the maximum dew point reached 21°C/70°F. Throughout its whole life the eye surface pressure averaged 948mb/28.00″, but at the time of maximum intensity the sea level pressure dropped to a low of 872mb/25.75″. The accompanying U-2 photographs, taken just an hour after the above record values were reached, comprise a historic revelation into the inner structure of this most devastating typhoon.

SERIES A

This photograph of typhoon Ida illustrates spiraling and ventilating mechanisms of the eye. An enlargement of the eye in this figure is presented as figure 1 in the B series. The propagating velocity of the storm was 11 knots toward the top of this figure and slightly left. The path of the reconnaissance plane was from top to bottom. Toward the left and right the top of the environmental cloud shield, figuratively speaking, projects cylindrically away from the mid-vertical of the figure. In other words, this figure is not only synoptically composite, being as if the photograph were taken over the entire area at the instant the aircraft was over the eye, but also temporally composite along the flight path. Although distance is therefore linear along the mid-vertical, the perspective from the aircraft does affect the field of vision, accordioning together distance toward either side from the center. To the west and east the sides of the figure are near the visual horizon approximately some 80–100 nautical miles orthogonally away from the mid-vertical of the figure.

When rectified the bands analytically best fitted a certain logarithmic spiral. Looking from above the eye and turning with the storm, we may observe from successive photographs, like this figure, that these bands rotate about the eye without any measurable radial motion. In this figure downward ventilation occurs from the spiral terminal at the rear of the eye.

FIG. 1

SERIES B

This series from typhoon Ida briefly illustrates the ventilation and rotation mechanisms of an eye and also its tilt. The eye is 9.4 nautical miles wide and 65,000 ft deep. During the eleven minutes between figures 1 and 2, the inner eye base has rotated 281°, the angle through which we have turned figure 2 clockwise "backwards" to facilitate their comparison. Whereas the north direction is toward the top in figure 1, it is to the left in

FIG. 2

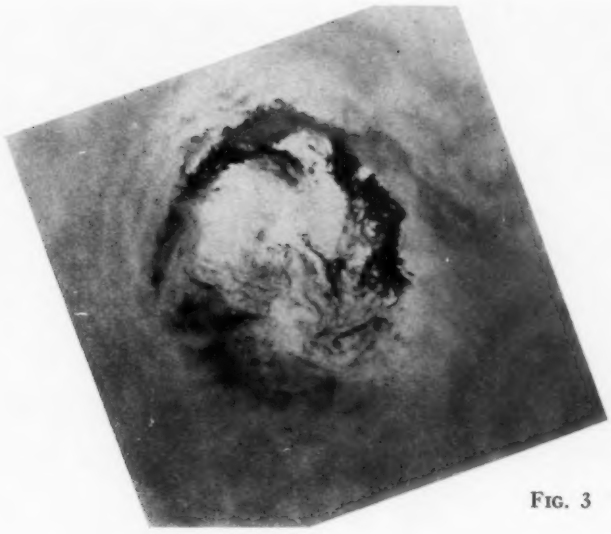


FIG. 3

figure 2. We have likewise turned figure 3 back 340°, through which the inner eye has rotated during the 14 minutes between figures 2 and 3. Within the eyes of these figures the features of the cloud debris and exposed surface of the ocean appear in roughly the same position in the photographs; the top of the debris, incidentally, is 7,400 ft. At its base, the inner part of the eye appears to have roughly a disk-like rotation, with some deformation and radial motion. During these two periods, the angular velocity decreases from 27°/minute to 24°/minute. Along a partially clear moat located inside the base of the eye wall, a band of rapidly-streaming air rolls and tumbles the cloud debris.

In figure 1 an active cloud bridge extends from the rear upper lip of the eye wall down into the inner eye. In figures 2 and 3, this bridge has become inactively disconnected from the eye wall. Ventilation mechanisms have characterized the modeled circulation of typhoon eyes. In the past, we have generally assumed that there was a more or less steady, symmetrical downflow from all quadrants into the eye of a typhoon. But the results here particularize the descent of clear air and cloud mass into the eye as a strong, periodic injection plunging locally over the rear upper lip of the eye wall, or from it, down into the inner eye, usually into its rear part.

The movement of Ida is toward the top of figure 1 and, roughly speaking, toward the upper left in figures 2 and 3. We have stereoscopically measured eye wall slopes by determining horizontal lengths of sun shadows on the lower cloud tops within the eye. During the time of these figures the solar elevation was 66–67°. The solar azimuth was toward the lower left in figure 1, the right in figure 2, and upper right in figure 3. In these figures shadow lines of the rim wall are rather sharp on the cloud debris top. These photographs also show that this small, propagating eye is entirely cylindrical, sometimes with an appreciably forward tilt; i.e., a periodic slope outward to the front of the storm. In the past the typhoon models have variously structured the eye wall as opening conically upward (Bergeron and Palmén), or vertically cylindrical (Mateno), or cylindrical below and conical above (Riehl), or as nearly vertical on its forward side and sloping outward to the rear (Malkus and Simpson).

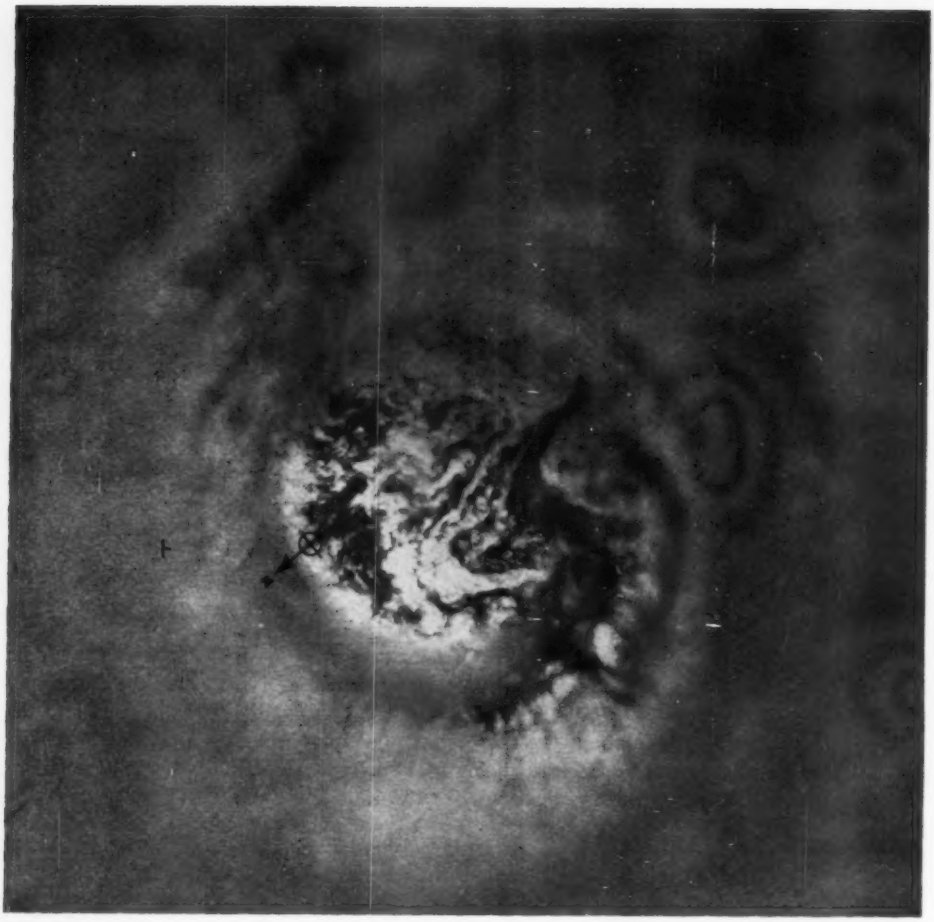
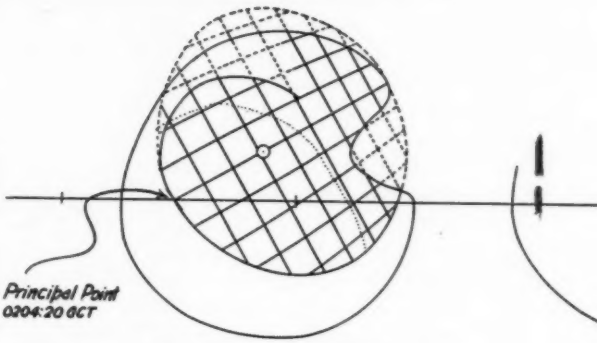


FIG. 1A

SERIES C

This series from typhoon Ida briefly illustrates a one-minute variation in the morphological dynamics of an eye from superior photographic reconnaissance. As shown by the overprints in figure 1, the straight path of the aircraft is from left to right, on a 220° heading. Thus, the north direction is toward the lower left. In figure 1*a* the principal point of the photograph is at the left edge of the eye base as indicated on the overprint. In figure 1*b* the principal or plumb point is over the environmental cloud shield a mile beyond the upper lip of the eye wall. The interval between figures 1*a* and 1*b* is exactly 55 seconds. These figures are synoptically



composite, as if taken over the entire area at the instant indicated beneath the plumb point. At 69,200 ft the perspective from the aircraft over the plumb points determines our

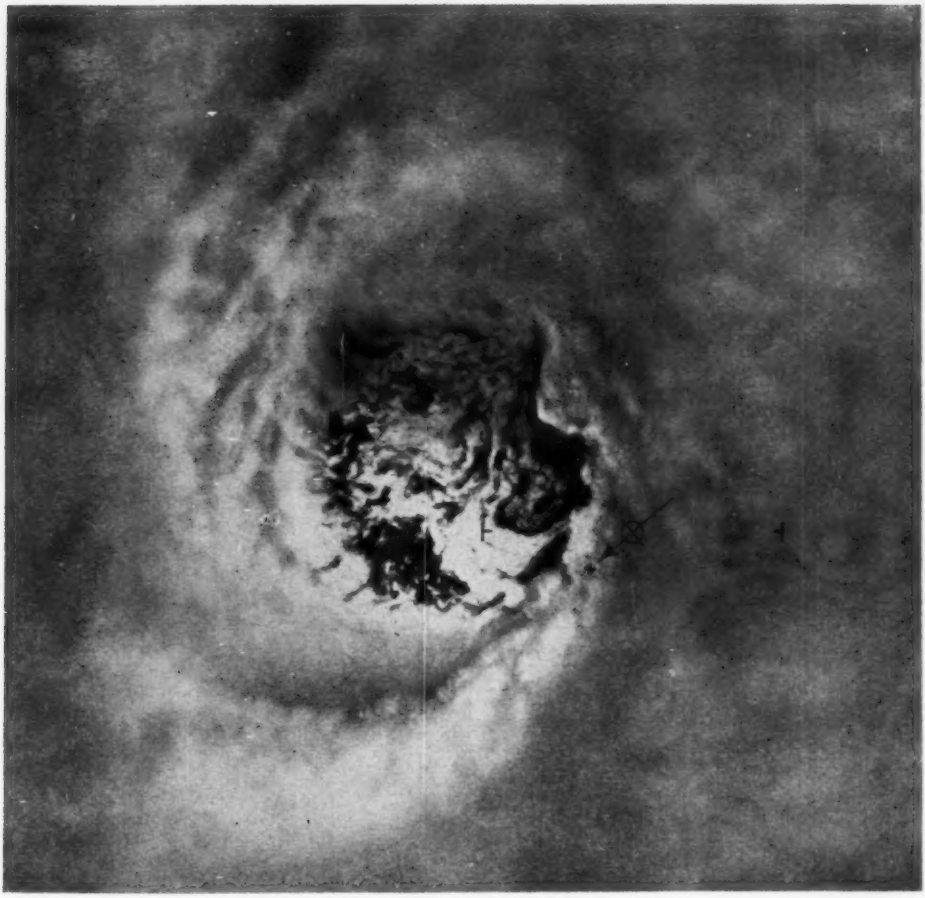
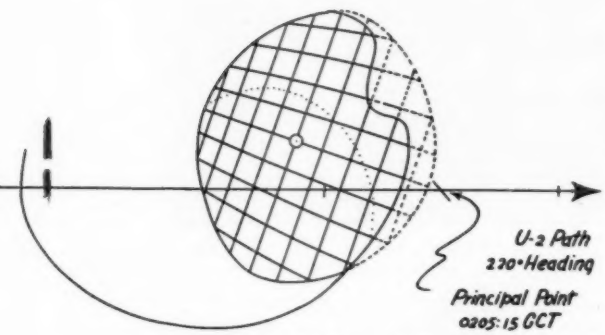


FIG. 1B



field of vision in figure 1. From these viewpoints the overprinted grids rectify the eye base at 7,400 ft, which is the top of the eye-cloud debris. Each grid square is 1 × 1 nautical mile. The grid drawn with continuous lines is in direct view; whereas, the dashed part is obscured, either by overhanging cloud or by the wall of the forward tilted eye. Solid, generally closed curves mark the outward limit of the eye, one at its base (7,400 ft altitude) and the other at its top (65,000 ft). Sides of eye wall lie between these curves in each figure. At its base the center of rotation is marked by a small circle in the overprinted grid.

Between figures 1*a* and 1*b* we observe a pronounced cyclonic rotation, an overall 18°/55 seconds. From such photographs, individually successive at 55-second intervals and successively paired at 10–15 minute

FIG. 2

intervals, we have measured instantaneous eye rotation rates. But more spectacular even than this high angular velocity is the ventilation of the eye taking place. Figure 1 shows the descent of clear air into the eye as a strong injection plunging locally over the terraced right upper lip of the eye wall, and from it down into the rear part of the inner eye. The downward cascading air backwashes the cloud debris in the eye base. Whereas the top of the backwashed cloud is at 7,400 ft, the overhanging upper lip of the

FIG. 3

eye wall over which the columned air has been dumped into the eye is above 60,000 ft. This jet ventilation disturbs the otherwise quasi-disklike rotation of the cloud pattern in the base. In figure 1*a*, moreover, the ventilating air reaching the sea surface has displaced the apparent center of rotation forward one mile. A close-up of the ventilation "tube" is shown in figure 2. Here, the black areas are the darkly shaded sea. The 60,000-ft high protuberance of cloud inward from the upper lip wall is at the upper right. Its rolled and scalloped edge indicates strong shearing.

We have attempted thermodynamically to interpret these kinematic processes of ventilation in terms of a partial heat budget for the typhoon core. They suggest, for example, how the internally stored lability energy becomes periodically adaptable to change or modification into work-producing forms of energy, as its state of unstable static equilibrium is periodically being disturbed by these downward injections of air in quasi-adiabatic descent into a warm core.

Almost as unusually remarkable as this evidence of the ventilation mechanism is that of the Rankine vortex in figure 1. Looking closely at the most upper-left part of the eye base in figure 1*a*, we can see a small, partially clear moat inside the base of the eye wall there. As seen from figure 1*a*'s principal point, a close-up of this area is shown in figure 3. The blackened areas are the darkly shaded open sea. The upper-left part of this figure is the vertical inside of the cloud wall; the lower-left, the horizontal top of the cloud debris at the eye base. At the inner boundary of the eye wall rapidly-flowing air rolls and tumbles the cloud debris. This super-speed rim around a disk-like rotating center forms the mechanisms for outflow and an exchange of mass and momentum between the energy-producing eye air and its kinematically excited cloud wall.

The Meteorological Observing Area at Mirny. All photos by Morton J. Rubin.

Inside Antarctica No. 6—Meteorology at Mirny

GORDON D. CARTWRIGHT AND MORTON J. RUBIN,
U. S. Weather Bureau, Washington, D. C.

ONE of the evidences of the excellent world-wide cooperation engendered by the International Geophysical Year was the exchange of scientists between the U.S.S.R. and the United States in the Antarctic. It was logical, and also gratifying, that this exchange first took place in the field of meteorology. At the Paris meeting of the Special Committee for the IGY in July 1955, the United States invited all nations involved in Antarctic research to join in the work of the IGY Antarctic Weather Central at Little America V, the main U. S. scientific station. As a result of this invitation, meteorologists of six nations—Argentina, Australia, France, New Zealand, South Africa, and the Soviet Union—participated.

The Soviet Union extended an invitation for a meteorologist to work with the Second Soviet IGY Antarctic Expedition based at Mirny. During 1957 and 1958 Messrs. Rastorguev and Astapenko, respectively, Soviet meteorologists who worked at Little America, shared with the authors the distinction of being among the very first to participate in an exchange of scientists between our two countries. It is encouraging to note that the exchange started in 1957 is still continuing in the Antarctic, and also for other disciplines. A few details of the Soviet Antarctic program in meteorology may be of interest to the readers of *Weatherwise*.

RELATIONSHIP TO THE IGY

Meteorology was the largest program during both the Second and the Third Soviet IGY Antarctic Expeditions. Soviet scientists had given careful attention to the CSAGI recommendations for the IGY, and the only standard IGY program not carried on was atmospheric chemistry measurements (carbon dioxide and particulate matter). Glaciology, another large program, was closely coordinated with meteorology. Frequent scientific meetings were held during the winter and helped stimulate interest in these interdisciplinary relationships. There was also full awareness of the interdependence of data taken by all countries working in the Antarctic, and intense interest was shown in the findings of other stations.

Of these stations Mirny, Oasis, and Vostok had the most consistent and complete meteorological programs. Vostok-I was replaced by Vostok; Oasis, Pioneerskaya, and Sovietskaya have been discontinued; Komsomolskaya has operated since early 1959 only as a summertime station. (The Lazarev station at 69°58′S, 12°55′E (24m) on the Princess Astrid Coast was established on 10 March 1959.)

THE WORK AT MIRNY

The leader of the Second Expedition was an oceanologist and that of the Third a meteorologist; both gave the fullest possible support to meteorology. The meteorological group was interesting because of the degree of specialization of its members. The heads of the meteorological groups in both cases were men of research caliber and long experience. Oskar Krichak of the Second Expedition was from the Forecast Institute in Moscow, and Viktor Bugaev was former director of the Tashkent Geophysical Observatory. Each group was made up of several "synopticians," meteorologists (physical meteorology), aerologists (including specialists in aircraft observations), and ordinary observers (who did the routine synoptic and hourly observations and reporting).

Mirny was both the main operational headquarters for the continental expedition and its principal scientific station. About 190 scientists and technicians wintered over on the Continent during 1957 and 1958, representing all geophysical disciplines and biology. About 125 of these spent most of the winter in Mirny, at the edge of the continental ice sheet, just on the Antarctic Circle. The base was set up at a point on the Davis Sea where small rounded rocky outcrops kept the ice sheet immobile. Some buildings were actually sited on rock, others on the ice itself. At the MET station the gradient of the ice sheet was about 3 meters in 100 downwards towards the sea and all the principal instrumental installations were made up-slope from the main buildings. Two main buildings house the office and most of the personnel. They were joined by unheated storage space for meteorological supplies.* Two field huts were set up near the observing site, a 40-meter square area, to house recording equipment and to protect personnel during observation periods; they were linked to the main meteorology buildings by field telephone. The balloon inflations shelter was combined with a large metal storage building, against which was erected a 12-meter-high square tower. This tower was designed and built during the Second Expedition to reduce the loss of balloons during high winds. Hydrogen gas was generated using a low pressure generator of simple design and the gas stored in large dirigible-shaped light fabric bags, having sufficient capacity for four ascents.

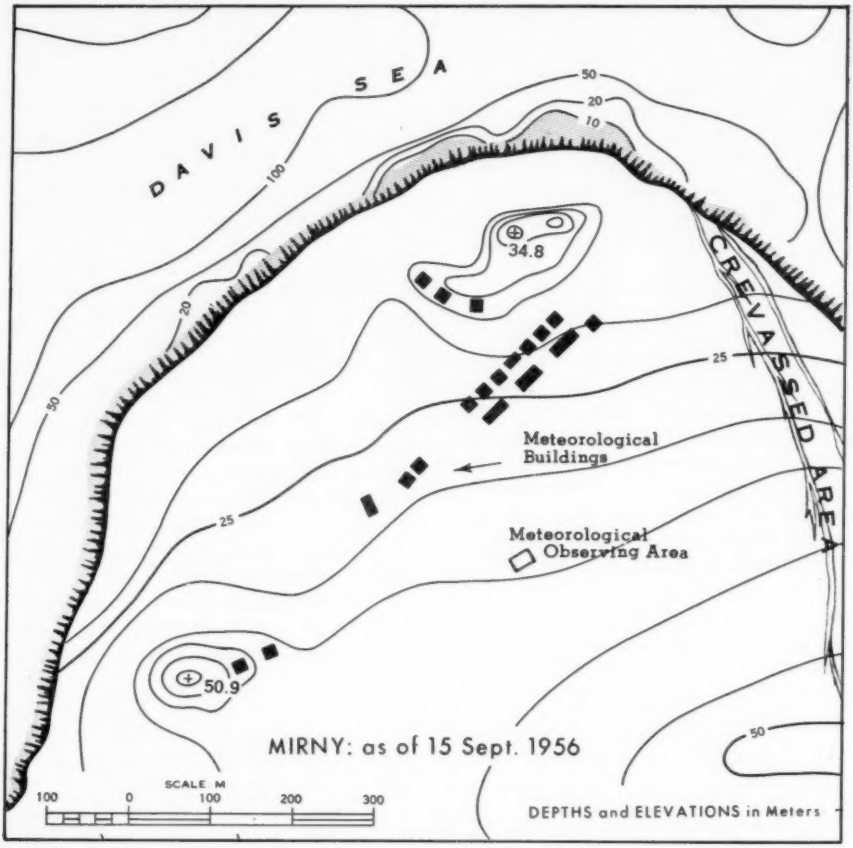
In addition to the rawinsonde ascents and the usual surface synoptic and hourly (aviation) observations, the meteorological program at the three main Soviet stations included most of the following: radiation total hemispheric, diffuse, direct, and radiation balance (net), all recorded continuously on multichannel recorders; wind, temperature, and humidity at selected heights from surface

* It was these buildings that were lost in the disastrous fire on 3 August 1960. Eight men, including Krichak, lost their lives.

TABLE 1

STATION DATA

Station	Location	Height (m)	Remarks
Mirny	66°33′S, 93°01′E	35	Open 13 Feb. '56
Oasis	66°16′S, 100°45′E	29	Open 15 Oct. '56; closed 17 Nov. '58
Pioneerskaya	69°44′S, 95°30′E	2,700	Open 27 May '56; closed 15 Jan. '59
Vostok-I	72°08′S, 96°35′E	3,140	Open 12 Apr. '57; closed 30 Nov. '57 replaced by Vostok
Vostok	78°27′S, 106°52′E	3,420	Open 16 Dec. '57
Sovietskaya	78°24′S, 87°35′E	3,570	Open 16 Feb. '58; closed 3 Jan. '59
Komsomolskaya	74°05′S, 97°29′E	3,420	Open 6 Nov. '57; after early '59 reopened only for summer operations



to 10 meters (these were not continuously recorded in all cases, but observations were made regularly); sub-surface temperatures at closely spaced intervals down to 4 meters (similar measurements were carried out to greater depths in connection with the glaciological studies); snow surface maximum and minimum temperatures; collection of snow crystals (intermittently). Aerological observations from aircraft were among the special studies carried out at Mirny.

THE AIRBORNE METEOROLOGICAL PROGRAM

The airborne meteorological program was extensive. A two-engine LI-2 (DC-3 type) was fitted out as a flying meteorological observatory, with a 12-channel variable-speed photographic recorder for the following observations: solar radiation (five filters for different wave lengths), optical measurements of cloud density (photoelectric cell and standard light source), total solar and sky radiation, reflected solar radiation. Two clock-driven meteorographs mounted ahead of the wing on each side of the airplane recorded pressure, temperature, and relative humidity. In addition, the following were observed directly: air temperature (electrical resistance thermometer and large spirit-thermometer), altitude (pressure and radio altimeter), ice-crystal and cloud-drop samples (through exposed oil-covered glass slides which were photographed through a microscope), cloud forms and surface phenomena. On several occasions equipment for measuring atmospheric electricity phenomena was placed aboard and flights were carried out over the

ocean, over the continental ice-cap and through low and middle clouds. The plane was fitted, also, with a mount for a vertically-oriented mapping camera.

In 10 months during 1958, 17 flights were made, usually with three observers aboard to attend to the instruments and to record the necessary data. Vertical soundings were made as the plane flew its course from a hundred kilometers over the ocean to 500 or more kilometers over the continent. On one occasion (22 April 1958) we accompanied a meteorological reconnaissance flight of about seven hours duration that took us over the site of Vostok-I, 3140 meters above sea level. At the time of our flight the station was not occupied, but we were able to determine that the temperature was −52° C (−61.6° F) only 23 meters above the surface, determined by radio altimeter, while the temperature at 200 meters was −36° C (−32.8° F). The surface inversion was marked by a very thin ice-crystal fog—perhaps produced by the presence of the airplane, although we had observed the thin fog before we broke down into the inversion—and the snow surface was somewhat obscured. In other portions of the flight we noted that the orientation of the primary sastrugi reflected a prevailing surface wind from 110°, while a secondary orientation showed a wind from about 170°. The Vostok-I station was where eight men wintered in 1957 on their way to the geomagnetic pole and had carried out a surface and upper-air observational program as well as glaciological observations. It was here, too, that a plane landed on 27 June 1957 (mid-winter night) to evacuate two sick men; the mean temperature for that month was −51.7° C (−61.1° F), the maximum −30.5° C (−22.9° F) and the minimum −67.8° C (−90.0° F).

ICE RECONNAISSANCE PROGRAM

One of the unique programs carried out by both the Second and Third Antarctic expeditions was the regular monthly reconnaissance of the distribution of the pack ice from the edge of the continental ice to the edge of the pack ice as much as 700 km from base. This program was carried out by LI-2 type aircraft with special ice observers and meteorological observers on board. In some instances the aircraft also was fitted with aircraft-type meteorographs, and vertical soundings were made at the limit of flight over the sea. Detailed and highly organized records of the character of the pack ice were kept by the ice observer and these were compiled in the form of a time analysis (monthly or bi-monthly) of the ice features over the areas surveyed regularly by the aircraft. This information seemed to have an interesting correlation with the prevailing weather conditions and a preliminary analysis of these features was undertaken during the Expedition. However, much more careful work with more data was likely to be required before any firm conclusions could be drawn. It was postulated by the chief of the meteorological group that the variation in the edge of the pack ice, as well as its character in the region off Mirny, showed the effects of the prevailing distribution of cyclones and anticyclones in this area.

AUTOMATIC WEATHER STATION

In November 1958 an automatic weather station, reporting surface wind, pressure, and

The lower part of the 10-meter meteorological tower shows exposure of temperature and humidity sensing elements which are connected to a multi-channel recorder.

TABLE 2

CLIMATOLOGICAL DATA: MIRNY 1956–1958

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Mean Temp. (°F)	30.4	23.4	15.3	11.5	8.2	1.2	2.7	−0.6	2.1	8.2	19.0	27.7	12.4
Max. Temp.	46.4	37.4	30.2	30.2	32	28.4	24.8	24.8	28.4	28.4	41	46.4	46.4
Min. Temp.	15.8	−2.2	−4.0	−14.8	−16.6	−27.4	−32.8	−40	−27.4	−25.6	−0.4	12.2	−40
Prev. Wind Dir.	107	130	133	130	127	150	123	147	117	103	123	100	124
Mean Speed (Kts.)	16.9	19.2	22.0	27.6	28.1	26.4	28.7	28.3	26.0	20.2	19.4	15.7	23.2
Max Speed (Kts.)	56	49	54	62	78	76	99	99	89	78	54	58	99
No. Days >29 Kts.	9	14	18	22	26	20	27	24	20	20	14	7	224
Station Pressure (Mb)	985.6	986.2	982.1	982.8	988.8	991.2	984.2	980.8	977.0	979.7	982.9	986.9	984.0 (29.06″)

TABLE 3

CLIMATOLOGICAL DATA: VOSTOK 1958

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Mean Temp. (°F)	−24.3	−48.3	−68.6	−83.2	−81.2	−90.2	−85.5	−97.2	−87.3	−73.8	−45.8	−28.1	−67.7
Max. Temp.	−9.4	−20.2	−52.6	−45.4	−45.4	−52.6	−47.2	−67.0	−49.0	−41.8	−29.2	−14.8	−9.4
Min. Temp.	−41.8	−76.0	−88.6	−99.4	−108.4	−113.3	−113.8	−125.3*	−115.6	−95.8	−76.0	−47.2	−125.3*
Prev. Wind Dir.	180	180	220	240	240	270	240	220	250	220	220	260	228
Mean Speed (Kts.)	8.9	7.2	9.9	7.8	10.1	9.5	9.7	9.1	10.5	7.8	8.1	7.4	8.9
Max. Speed (Kts.)	27	18	19	19	29	49	25	25	25	23	25	21	49
No. Days >29 Kts.	0	0	0	0	1	1	0	0	0	0	0	0	2
Station Pressure (Mb)	630.0	627.6	624.8	628.0	627.7	623.1	623.2	614.3	613.7	620.2	624.0	626.5	623.6 (18.41″)

* World record minimum air temperature, recorded 25 August 1958. On 24 August 1960 a new record minimum of −88.3° C (−126.9 °F) was recorded.

temperature data, was established on Drygalski Island (65°43′S, 92°30′E), a 350-meter-high ice-dome formed over a submarine rise in the Davis Sea, some 75 km north of Mirny. After a period of testing at Mirny, the equipment and several technicians had been flown to the island. Ten days were occupied in installing and regulating the equipment, which transmitted pressure over a 100-mb range, wind speed from 1 to 16 meters per second, wind direction to 32 points, and temperature from +6° to −88° C (+42.8 to −126.4° F). On Drygalski Island the sastrugi patterns showed that the prevailing winds were easterly. Orographically induced low clouds and fog were common over the island. During the short period of occupation, 40 meters per second (90 mph) winds were experienced.

Earlier in the year a similar automatic weather station had been hurriedly installed on the ice slope between Mirny and Pioneerskaya stations during a glaciological traverse. The equipment soon ceased transmitting, however, probably due to mechanical failure induced by strong katabatic winds and drifting snow so common in the region.

THE PROGRAM AT OASIS

The Soviet station at Oasis was of particular importance because of the unusual topographic features that prevailed. Here was an extensive area of exposed rock virtually snow-free during most of the year and contiguous to a configuration of the continental ice sheet which produced especially strong winds under certain synoptic pressure distributions. The freezing and thawing of fresh water lakes formed by the melt water from the continental ice sheet afforded a very interesting laboratory for study of the effects of seasonal changes in radiation on the ice regime. A full program of radiation measurements in various parts of the Oasis area was pursued by a small staff of six men. Soil temperature measurements at a number of depths also provided important data in the study of the transfer of heat to and from the fresh water lakes and the morainic material which comprised most of the Oasis area.

These programs were of particular interest in glaciological studies as well as in studies of frozen ground (a subject of great importance to Soviet scientists).

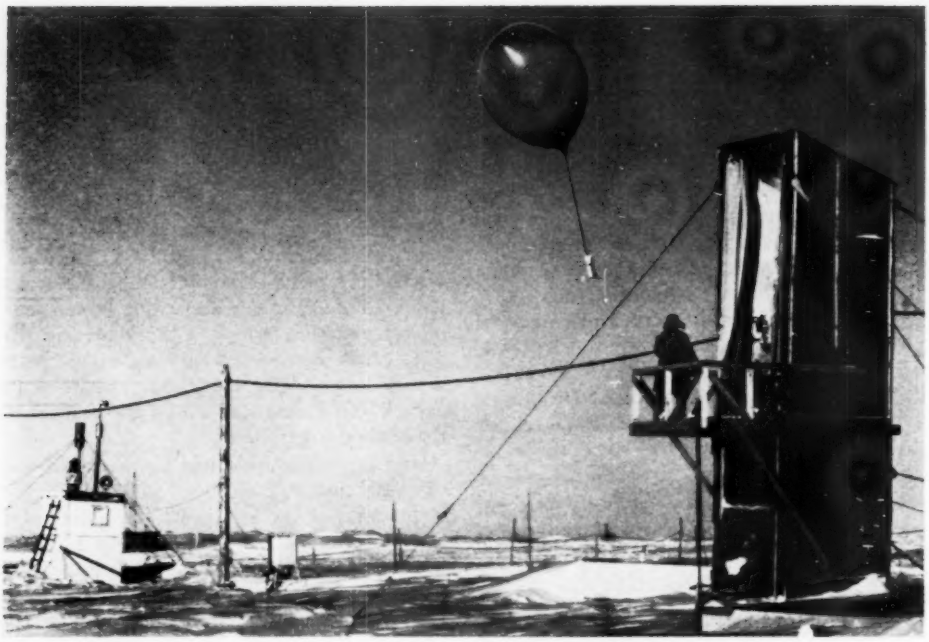
CLIMATIC CONDITIONS

Generally, the temperature at Mirny (Table 2) is relatively mild for Antarctica, excluding the Palmer Peninsula. However, the relatively high frequency of strong winds makes difficult the task of meteorological observers and all others who have to be out-of-doors. During the winter of 1958 there were 13 days with wind force above 60 knots. On one such occasion (23 July 1958) the pressure fell 21 mb in 6 hours, and 36 mb in 24 hours. Safety lines were strung from meteorological headquarters to the observing site some 200 meters upwind, and later were installed around the camp after two incidents of men losing their way within the confines of the camp during blizzards.

The prevailing wind was between east and southeast, an angle of about 30 degrees to the main slope of the ice sheet; these also were the direction of the strongest winds, which appear to be due to the eastward passage of storm centers north of the station and the reinforcement of the gradient winds by the katabatic effect. Use of the balloon release tower greatly increased the record of successful launchings (only two observations were missed in two years because of hurricane force winds), even though some occasions required the launchings of as many as four balloons before one was successful!

Stations on the high ice-dome such as Vostok, Komsomolskaya, and Sovietskaya were not bothered much by drifting snow as were the coastal and ice-slope stations. Their difficulties arose from and were associated with altitude and low temperatures that severely restricted strong and prolonged outdoor physical activities. Long hours and months of darkness, too, played their role. Balloons for pilot and raob ascents failed prematurely because of low temperatures encountered from the surface to the stratosphere, although preconditioning the balloons with heat and diesel fuel baths helped somewhat.

At Pioneerskaya station, as at Mirny and Oasis to a lesser extent, the strong winds and drifting snow made impossible the determination of how much snow was falling and how much was drifting. Crude equipment for measuring drifting snow was imprecise, and snow gauges were useless; only measurements



A radiosonde release from the specially constructed balloon inflation shelter.

of net accumulation against arrays of stakes gave reliable figures anywhere.

RESULTS OF SPECIAL PROGRAMS

A number of special studies were carried out by the members of the Soviet Antarctic Expeditions. These were meant to point out the character of the meteorological processes in the region and to help throw light on some exchange processes in respect to the atmosphere-ocean-ice complex. Synoptic and climatological analyses as well as the study of regional features, radiation balance, ice-mass movement, katabatic winds, and turbulent exchanges have been made by Soviet scientists, and the results have been presented in the literature. In general, they are similar to programs carried out by other countries. There are, however, two special studies that appear to be unique to the Soviet expeditions. One, an airborne radiation program, extended over a period of several years; the other, an airborne study of the atmospheric electrical field, was carried out only in 1958.

The airborne radiation program provided data for determining the short-wave radiation balance in the troposphere, as well as the albedo of the underlying surface of the continental ice and the Davis Sea, and the albedo of clouds. It was found that summertime mean values of atmospheric heating due to absorption of solar radiation were as shown in Table 4. Computations of cooling in the free atmosphere due to radiation under clear conditions gave about the same order as the radiative heating.

From the airplane observations the mean value of the albedo of the ice slope was found to be 80 per cent for sun height of 25–35°; the albedo decreased as the solar altitude decreased, probably due to the presence of snow sastrugi that shade the surface under conditions of low sun. The mean albedo of

TABLE 4

SUMMERTIME MEAN VALUES OF ATMOSPHERIC HEATING DUE TO ABSORPTION OF SOLAR RADIATION

Surface	100 m–2 km	2–4 km
Open sea	0.034° C hr^{-1}	0.026° C hr^{-1}
Young sea ice	0.023° C hr^{-1}	0.010° C hr^{-1}
Continental ice-slope	—	0.033° C hr^{-1}

young sea ice was found to be 65 per cent. The albedo of the open sea varied as the roughness; in calm conditions with solar height 10°, the albedo was 33 per cent; with small waves and solar height 30°, the albedo was 11 per cent. The mean albedo of stratocumulus clouds, which are the most frequently observed cloud form over the sea, was 62 per cent. Altocumulus clouds with a thickness of 250–300 meters have an albedo of 60 per cent, while altostratus clouds, which predominate over the ice slope, have an average albedo of 40–60 per cent.

A comparison of the atmospheric electrical potential gradient with pressure systems over the ocean shows that the potential gradient is increased in the leading portion of a cyclone and in the rear of an anticylone, while the gradient is decreased in the rear of a cyclone and leading portion of an anticyclone. Presumably this is explained by the regime of vertical motions in the pressure systems. Middle and upper clouds do not appear to affect the potential gradient, but lower clouds tend to decrease it by as much as 30 per cent. On the continental surface itself, the principal variations are due to wind conditions, cloudiness and the monthly and annual variations of gradient. With an increase of wind speed from 10 to 70 knots, for example, the positive value of the gradient increased; but with wind speed greater than 70 knots, the potential gradient changed sharply in sign and value, reaching negative values of 10's of thousands of volts per meter. Large positive and negative values of space charge density were noted that were several times greater than the space charges observed in thunderstorms elsewhere in the world. The sign of the space charge depended mainly on the wind velocity, with large negative values observed at wind speeds above 70 knots. It was also noted that the current from sharp points during snowstorms tends to reduce the negative charge of the earth; this is contrary to measurements obtained from other

The working area inside the meteorology building.

continental regions, but supports data from Cambridge, England, during stormy periods.

METEOROLOGICAL ROCKETS

A few meteorological rocket soundings were made from the Soviet research vessel *Ob* during the 1957–58 supply season. Two of these were made at Mirny and others at points around the periphery of East Antarctica and the Indian Ocean. These rockets reached to about 50 kilometers (31 miles) and provided temperature, pressure, and wind data from the middle stratosphere.

These few highlights illustrate the comprehensive and detailed character of the Soviet program for meteorology in the Antarctic. We cannot close this account without mention of the effective working relationships and cordial personal associations that existed between us and our Soviet colleagues during the period of our individual assignments. It was both an interesting and rewarding experience that has given us a better understanding of Soviet science and scientists. This, too, is another IGY dividend.

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1. Scientific Conference on the Problems of Antarctic Meteorology (abstracts of reports). Moscow, 26–28 October 1959. USSR Hydrometeorological Service.
2. A. V. Nudelman. Soviet Antarctic Expeditions 1955–1959. USSR Academy of Sciences, Moscow, 1959.

Antarctic Positions Open

Editor:

Once again we are recruiting replacement personnel for duty in the Antarctic. Any assistance you can give us will be greatly appreciated. Tentatively, the following staff is needed:

1	GS-13	$10,635	Meteorologist
4	GS-12	$ 8,955	Meteorologists
2	GS-11	$ 7,560	Meteorologists
2	GS-9	$ 6,435	Meteorologists
5	GS-11	$ 7,560	Electronic Technicians
1	GS-11	$ 7,560	Sup. Meteorological Technician
8	GS-9	$ 6,435	Meteorological Technicians

The positions are in the Excepted Service. Appointment will be for a period of 18 to 24 months including a rather extended period of training and indoctrination in the United States. Incumbents will serve approximately one year actually in the Antarctic. Training has been tentatively scheduled to begin as follows:

about 6–12–61	GS-11	Sup. Meteorological Technician
about 7–10–61	GS-13	Meteorologist
about 7–10–61	GS-12	Meteorologists
about 7–10–61	GS-11	Meteorologists
about 7–10–61	GS-11	Electronic Technicians
about 8–7–61	GS-9	Meteorologists
about 9–8–61	GS-9	Meteorological Technicians

Departure from the United States will be in October or November 1961 and return will be in December 1962 or January 1963.

In addition to the regular per annum salaries, an allowance approximately $2800 is paid for Antarctic assignment. Also quarters, subsistence, travel and polar clothing are furnished free of charge.

In view of great scientific importance of the program and the various opportunities it affords, all qualified persons are urgently requested to give serious thought to applying for an Antarctic assignment.

Additional information and application forms may be obtained by writing, Chief, Personnel Management Division, U. S. Weather Bureau, Washington 25, D. C.

J. J. DAVIS, *Chief*
Personnel Management Division

It is generally agreed that Dr. John Lining of Charleston, South Carolina, deserves the honor of being the first in the British American colonies to make continuous daily weather observations with instruments over an extended period of time. His thermometer shelter was located at his place of residence at King and Broad Sts. in the heart of old Charleston.

Lining's valuable records commenced in April 1737 and continued at least until 1753. Usable summaries of these, as well as descriptions of his instruments, were published in the *Philosophical Transactions* of the Royal Society in London in 1748 and 1753.

John A. Cummings, meteorologist in charge of the Weather Bureau office in Charleston, wishes to call the attention of *Weatherwise* readers to current plans to restore the original Lining residence to its former colonial elegance:

"The Lining building contained a Drug Store until a few months ago when Dr. Poulnot, the last owner, decided to retire. He sold the building to the owners of Berlin's Mens Store, across the street, who wished to improve the property to enhance the appearance of the neighborhood.

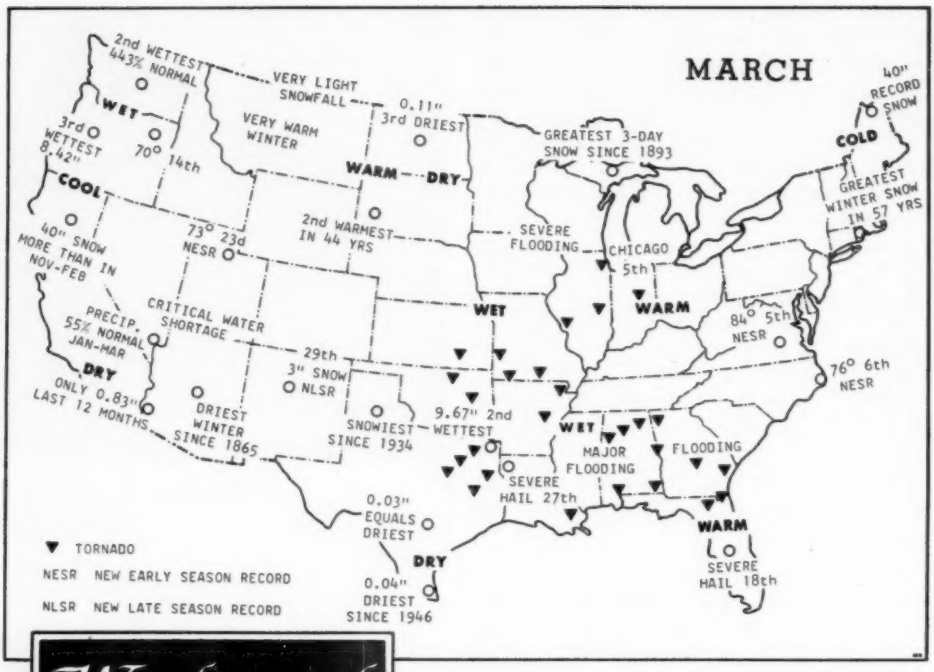
"A strong sentiment, however, was aroused by the public for the preservation of the building as a historical monument, and the Berlin brothers agreed to give the Preservation Society of Charleston an option to repurchase the property at their cost. The Society proposes to restore the building to its original appearance, most of which has been preserved and to use a part of the lower floor of the building as headquarters for the Society. About 70 per cent of the required funds have been raised at this time, but some outside help is necessary if this worthwhile project is to be accomplished. It is, therefore, hoped that members of the American Meteorological Society and meteorologists in general will contribute to the preservation of this landmark in world climatology. Checks for contributions should be mailed to the Preservation Society of Charleston, P. O. Box 521, Charleston, South Carolina."

Photos courtesy of *The Charleston Evening Post* and *The News and Courier*.

Present

America's First House of Meteorology

Restored



Weatherwatch

Data by Office of Climatology, USWB.

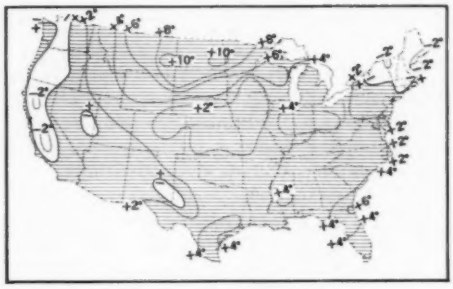
A Mild, Damp March—Cold, Stormy April

DAVID M. LUDLUM

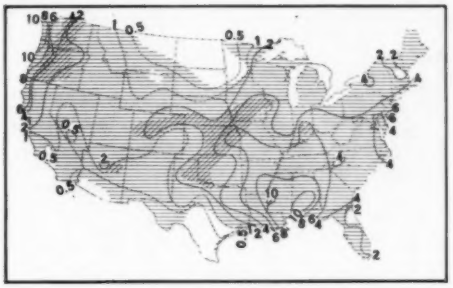
March 1961 was generally a warm month in direct contrast to conditions just one year ago when much of the interior of the United States experienced the coldest March in recorded weather history. Only a strip of the Pacific Coast mountain area and the extreme Northeastern United States had below normal readings this year. There were the usual number of March storms, but none achieved a noteworthy rating. Tornadoes were present, but in physical size they were small and in extent of damage, minor. The most widespread storm activity took place in a strip from the central Rockies northeastward to Lake Michigan where a series of Great Plains disturbances produced several heavy snows in a section that had been almost snowless during the preceding winter months. Later the melt of this snow plus substantial rains sent streams in the contiguous parts of Iowa, Minnesota, and Wisconsin into serious flood stages, to make the principal weather headlines of the month.

CIRCULATION—The fast westerly flow pattern that had dominated the upper-air pattern during the greater part of a warm February carried over into the first days of March. As the month opened, a complicated storm system moved eastward across southern Canada: in its rear a surge of polar air invaded most of the Far West to end temporarily the abnormally warm winter regime there—to the south and east of the sprawling frontal system, warm tropical air was pumped northward into a large ridge of high pressure over the Ohio Valley, the Lower Lakes, and the Atlantic seaboard. From the 4th to the 7th temperatures in this large warm sector reached record date levels, and in some places the warmest so early in the season marks were set.

A circulation change became evident about the 7th, and thereafter westerly flow dropped to a low ebb for a two-week period as cyclonic activity in the central part of the continent became the principal feature of the weather maps. Convergent flow around these low pressure centers aloft produced mainly cloudy skies and cool weather with frequent periods of rain and snow. On the 14th, in addition to a low feature over the Great Lakes, storms of more than average intensity were to be found on both the middle Pacific Coast and the middle



Departure of Average Temperature from normal in degrees Fahrenheit. USWB chart.



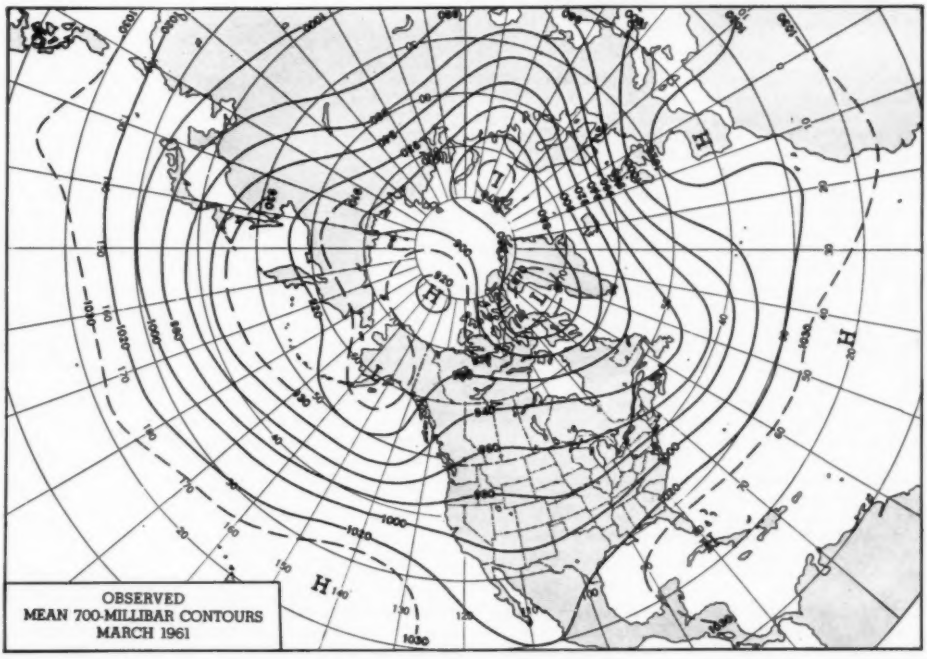
Total Precipitation in inches. USWB chart.

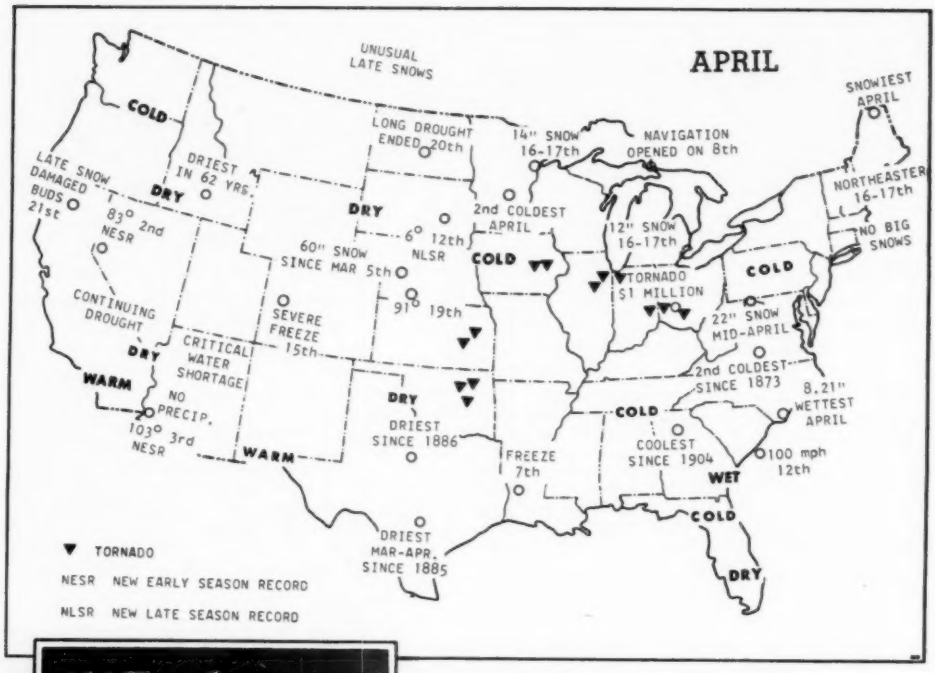
Atlantic Coast with widespread precipitation. The western storm controlled the air circulation over much of the nation during the next nine days as it drifted eastward in a leisurely transcontinental journey. After bringing a variety of weather to all sectors, the upper-air disturbance passed off the East Coast on the 24th and surface conditions improved with its disappearance. It was during this period, from the 18th to the 22nd, that the index of westerly flow sank to its lowest level of the month.

Despite the presence of low centers over the United States, arctic air did not penetrate to the United States with any regularity as a fast flow of Pacific air through southern Canada shielded areas to the south. Parts of the northern Plains experienced their seventh consecutive warmer than normal week. The track of anticyclones during the month ran from the western shores of Hudson Bay, southeastward to Ontario, and then eastward through Quebec. Only the extreme Northeastern United States felt the chilling blows of these northern intruders. The arctic outbreak of the 17–18th dropped

(*Continued on page 124*)

The upper-air map below shows the pattern of air flow for March at about 10,000 feet, on which the average weather largely depends. The contours lines represent the mean height of the 700 mb. pressure level. Figurs are in tens of feet: 1020 = 10,200 ft., 980 = 9,800 ft., etc. Chart by Extended Forecast Section, USWB.





Weatherwatch

Data by Office of Climatology, USWB.

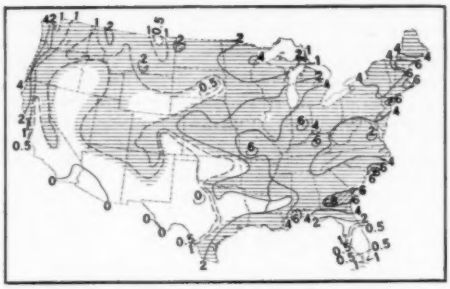
A major reversal in temperature regime marked the transition from March to April. Whereas the balmy breezes of an early spring covered the greater part of the interior of the United States and southern Canada in March, the early and middle periods of April brought a return to wintry conditions with numerous records set for lowest-so-late-in-the-season temperatures as well as for heavy late spring snowstorms. In parts of the northern Plains the temperature reversals following one of the warmest winters were spectacular—from *much above* in March to *much below* in April. Central and northern Florida, too, where the winter also had been relatively mild, suffered the same degree of change. Only a strip along the California coast and the Mexican border received more than the normal thermal input in April 1961.

The shift in the precipitation pattern also showed great magnitude—regions predominately wet in March were now mostly dry and vica-versa. The very large area of *heavy* precipitation covering most of the Mississippi Valley and the central Gulf States, where serious floods occurred in March, shrank to less than half its former size and shifted to the Northeast. Drought conditions once again returned to the western third of the nation where 80 per cent of the area had *very light* rainfall.

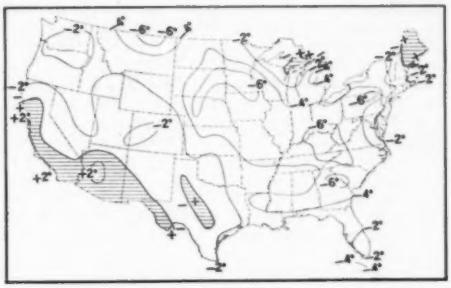
CIRCULATION—The air flow pattern of April differed markedly from that of March as was evidenced by the realignment of pressure areas both at sea level and aloft. The most significant shift in the surface contours took place in the northeastern Pacific Ocean off the coasts of British Columbia and Washington where for most of April anticyclonic ridge conditions replaced the cyclonic systems prevailing in March. The change became noticeable on the 4th–5th when rising pressure offshore turned the upper-air flow into the northwest. A stream of polar air took over from the long dominate Pacific air masses which had produced one of the mildest winters of record over the northern Plains. Temperatures in Montana dropped below normal at the start of April for the first time in seven weeks.

There were three major phases to the air flow across the country in April. After the brief opening period of westerly air streams bringing in mild Pacific air, a stormy period ensued for the central parts of the continent with some notable weather headlines featuring the middle two weeks.

The outstanding meteorological event of the month centered around the disturbance which moved in a circuitous course from Alberta on the 12th to Cape Cod on the 18th. When swinging down into the central Great Plains, cold air from the Arctic pushed into the circulation on the 14th and 15th with the result that a spectacular 24-hour deepening took place from 1000mb/29.53″ on the 15th to 982mb/29.00″. At the same time the center, stalled by a strong blocking ridge over northeastern Canada, made an unusual loop of 24 hours duration over lower Michigan before resuming its normal movement



Departure of Average Temperature from normal in degrees Fahrenheit. USWB chart.



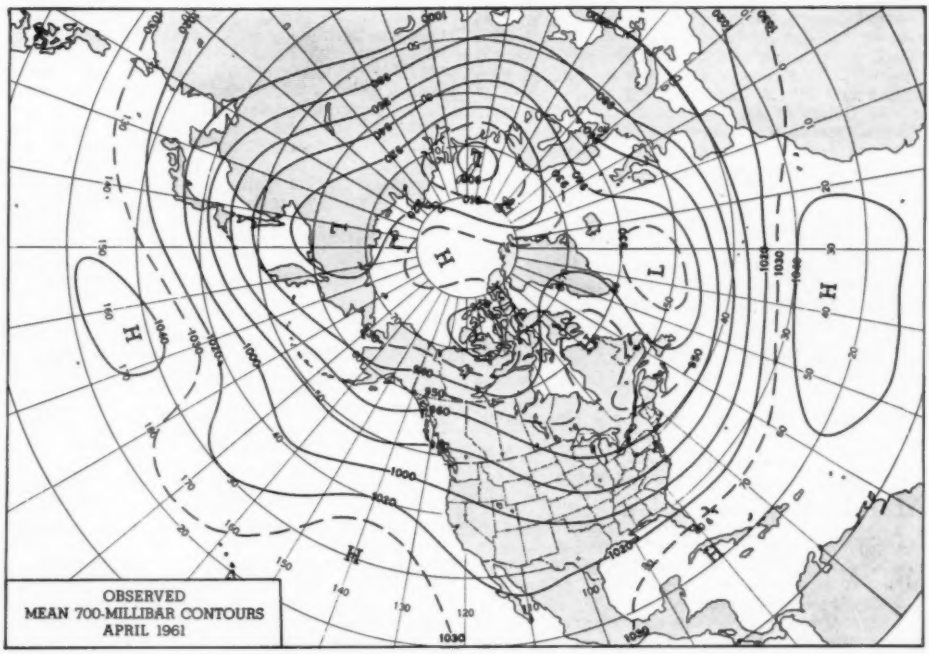
Total Precipitation in inches. USWB chart.

eastward. At this manoeuver cold air moving completely around the center created record low date temperatures and produced unusual mid-April snow amounts in all quadrants. Chicago Midway Airport measured a snowfall of 6.8″, the greatest for so late in the season in Weather Bureau records, and much of southern Michigan had 12″ and more.

As this severe storm filled and drifted eastward into the Atlantic on the 18th, the third phase of the April weather regime opened. A marked trough feature took up a position over the Pacific coastal area to shift the scene of main storm activity westward. Some much-needed late season rains fell in California and Oregon and parts of the Plateau and northern Rockies. Meanwhile the Bermuda High built up in the Atlantic to create a western trough-eastern ridge situation shifting air flow east of the Mississippi River to a southerly component. This produced a belated spring warm spell in the East—at New York City the mercury from the 22nd to the 26th climbed appreciably above normal for the first time in April.

U. S. BRIEFS

March–April rainfall at San Antonio only 0.35″, the lowest since records began in 1885 . . . precipitation at Phoenix for last 6 months only 19% of normal . . . navigation season at Soo Locks commenced on 8th . . . northeaster on 16–17th at Portland brought 2″ rain and caused some tidal flooding along Maine coast . . . wet snow of 9″ on 23rd at



Williston, N. D., caused damage to communications . . . Huron's 6° on 12th equaled lowest ever in April . . . Fresno's 91° on 3rd, the warmest so early . . . Grand Rapids had 12.2″ snow on 16–17th, the greatest ever in April . . . pressure dropped to 29.00″ at Flint, Michigan, on 16th . . . Yuma had 103° & 104° on 3–4th, for new early records . . . Abilene's trace was driest April since records began in 1886 . . . early fruit blossoms killed at Mount Shasta, Calif., on 18th, destroying crop . . . April second coldest at Lynchburg, Va., since 1873 . . . Rochester, Minn. also had second coldest April . . . rain on 20th and rain-snow on 23rd broke drought at Bismarck extending back to September 1960 . . . wind gust of 84 mph from SSW at Cape Hatteras on 10th . . . freeze on 15th caused heavy loss to apricots at Grand Junction, Colo. . . . winter total snow of 19.2″ at Green Bay, Wisconsin, was lowest for any winter . . . total of 8.21″ was wettest April ever at Wilmington, N. C. . . . wind gusts of 100 mph from SE on islands near Charleston, S. C., on 12th . . . tornado near Dayton, Ohio, at 1600 on 25th caused $1 million damage, no deaths . . . Atlanta had coolest April since 1904 . . . at Boise, Idaho, it was the 3rd driest in 62 years with 0.22″ . . . Buffalo's 13″ snow was 4th heaviest since 1870 . . . Caribou's 24.4″ was heaviest in 20 years of record there . . . seasonal snowfall of 81.3″ at Harrisburg far exceeded previous record . . . Cedar River in Iowa in serious flood early April . . . Wabash rising to critical levels in Indiana at month's end . . . many small tornadoes throughout month as far north as Indiana.

CANADIAN BRIEFS

One of the driest and warmest Aprils on record in northern Quebec . . . mean temperature at Nitchequon was 31°, some 12° above normal, and precipitation was 0.21″, only 32% of normal . . . in Northwestern Canada, the lower Mackenzie Valley was extremely cold with above normal snowfall . . . Inuvik, NWT, at −5°, averaged 11° below normal with 20″ snowfall . . . maximum temperatures were as high as the low 70's in the southern interior valleys of British Columbia and along the north shore of Lake Erie in Ontario . . . lowest temperature in the nation was −47° at Inuvik . . . freezing was experienced in all of Canada except a coastal strip in British Columbia . . . at Alert, NWT, it failed to rise above 15° . . . above normal storm activity across most of southern Canada . . . in B. C., Prince Rupert had more than 10″ rainfall and Vancouver had the dullest April in 15 years . . . cool, dry, and windy on the Prairies although severe storms gave Calgary 13″ snow on 18–19th and Brandon 18″ on 25th . . . in Eastern Canada the month was dull, cool and damp . . . Clear Creek in Ontario had as much as 6.50″ rain . . . in the Maritimes Chatham, N. B., reported 51″ snowfall in April to boost winter total to 200″, both new records . . . Goose Bay in Labrador had only 3″ in April, a new low extreme.

March (*Continued from page 121*)

the mercury below zero in New England and northern New York, making the week ending the 20th the coldest of the month. Departures were as much as nine degrees below normal there.

The final few days of the month produced a return to conditions existing during the first part of March: a cool West, warm East regime. On the 24th a trough cut into the Pacific Coast and Plateau states while a substantial ridge again built up over the eastern Great Lakes and Appalachian Mountain area. On the 26–28th locations in the East had their first sample of springlike conditions since the 7th. As March drew to an end, another closed low circulation in the upper-air developed in the Southwest and drifted eastward across the Upper South to bring a melange of early spring weather types, much to the discouragement of those eager for the commencement of the outdoor season.

U. S. BRIEFS

A tornado skipped across Chicago's South Side about 1700 on the 4th, causing one death and 155 injuries. Property damage estimated at $7 million, and great disruption to traffic and normal life. . . . Cape Hatteras had 76° on the 4th for a new early season record. . . . None of the usual blizzards or northerly gales visited northwestern Montana this winter. . . . A warm month along the Gulf brought the azaleas to full bloom week of 19–25th at Mobile. . . . Kansas City's 6.66″ was the wettest March since records commenced. . . . The worst hail storm of record at Shreveport caused $1 million damage to 10,000 buildings; stones as large as soft balls fell, some measuring 4.5″ diameter at weather station. . . . A March snowfall of 0.8″ at Sheridan, Wyoming, tied the all-time low mark; lowest temperature in a very mild winter there only −7°. . . . Green Bay's 17.7″ winter snowfall to end of March was the least of record for that period. . . . A 11.2″ wet snowfall on morning of 8th caused severe traffic jams at Milwaukee. . . . Only a small patch of solid ice remained at month's end as start of navigation season at Buffalo neared. . . . Marquette had 21.2″ of snow in three days (4–6th), the second greatest fall for such a period at the Upper Michigan location. . . . New daily high established at Richmond on 4 consecutive days (4–7th), highest 84°. . . . At Mt. Shasta, Calif. (3500′), 40.2″ of snow fell to reverse previous winter trend, but greatest accumulation at observation time was only 7″. . . . Alpena, Michigan, had greatest 24-hr snowstorm since 1947 with 11″ on 8–9th. . . . Rainfall at Phoenix, Arizona, since November only 21% of normal. . . . Severe storm on 27th dropped 1.69″ of mixed precipitation on Duluth to cause floods and hazardous driving conditions. . . . On 22nd Williamsport, Penna., had a heavy snowshower with large flat platelets of snow falling, some measuring 3″ and more across. . . . Caribou, Maine, had greatest March snowfall of record: 39.7″. . . . Blowing dust and sand closed some highways near Yuma, Arizona, on 15th. . . . San Antonio's 0.03″ precipitation tied the previous low March record. . . . Floods on rivers in eastern Iowa near Waterloo caused $70 million damage on 27–30th. . . . Mississippi at Lacrosse, Wis., reached highest stage since May 1954. . . . Rapid City, S. D., had second warmest March in 44 years of record. . . . Norfolk, Virginia, reached 84° on 6th for record warmest so early in season. . . . At Devil's Lake, N. D., March was unusually mild, dry, and pleasant; temperature 7.2° above normal, only 0.14″ precipitation. . . . Boston failed to have a major snowstorm for the first time since 1955. . . . Des Moines had its wettest March of record: 5.37″ of precipitation included 16.4″ snowfall. . . . March at Charleston, S. C. was generally warm, rather windy and wet, but very springlike and pleasant; 86° on 7th was new early season record. . . . Tornadic conditions at

Tulsa on 5th and 26th; golf ball size hailstones on 5th. . . . Three unusually heavy spring snowstorms at Amarillo, Texas, totalled 14.7″, the heaviest since 1934. . . . Another very dry month at Reno (0.40″) further depleted water supplies and indicated very critical water shortage this summer, the worst in 25 years.

CANADIAN BRIEFS

Parade of Pacific storms kept B. C. relatively warm and moist. . . . Vancouver and Victoria were warmest cities in Canada with 46° average. . . . 18.58″ precip. at Estevan Point, B. C. wettest for the country. . . . an intense Pacific depression on 5th dropped barometer to 28.86″/977.2mb at Victoria, equaling the lowest ever for March. . . . Prairie Provinces were mild and dry without any major arctic outbreaks. . . . a dozen stations had only traces of precipitation. . . . snow cover mostly gone from southern Prairies at month's end. . . . first two weeks of March very stormy in Ontario and Quebec. . . . 72° at Niagara Falls on 28th the warmest March reading for all Canada. . . . Toronto had heavy snowstorm with thunderstorms and gusts to 60 mph on 8th. . . . Atlantic Provinces battered by many coastal disturbances. . . . Sydney's snowfall of 71″ was record for any month of any year. . . . 16″ fell at Gander Airport on 11th to set new 24-hr. record. . . . Magdalen Islands in Gulf of St. Lawrence had 61″ snow on the ground at end of month. . . . many communities either ice-bound or snow-bound. . . . cold vortex persisted over eastern Arctic all month. . . . Eureka had a mean temperature of −40° for March. . . . Arctic Bay and Coppermine averaged 18 degrees below normal. . . . many arctic stations reported only a trace of snowfall in March.

Atlantic Hurricanes

(*Continued from page 101*)

tion for the hurricane (building construction, precautions, etc.); regional hazards and, finally, research on tracking and control, etc.

An appendix gives a tabulation of all tropical cyclones in the U. S. and Texas from 1635 to 1958, arranged by regions, with damage and intensity data, and a glossary of meteorological terms used in the book, plus an excellent list of references to recent literature, an author and a detailed subject index. A great deal of credit is due to Banner I. Miller for many contributions to this invaluable book on a subject that is of universal interest even to those who have never experienced the destructive forces of the tropical cyclone.

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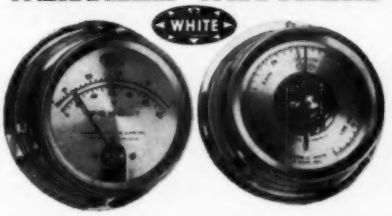

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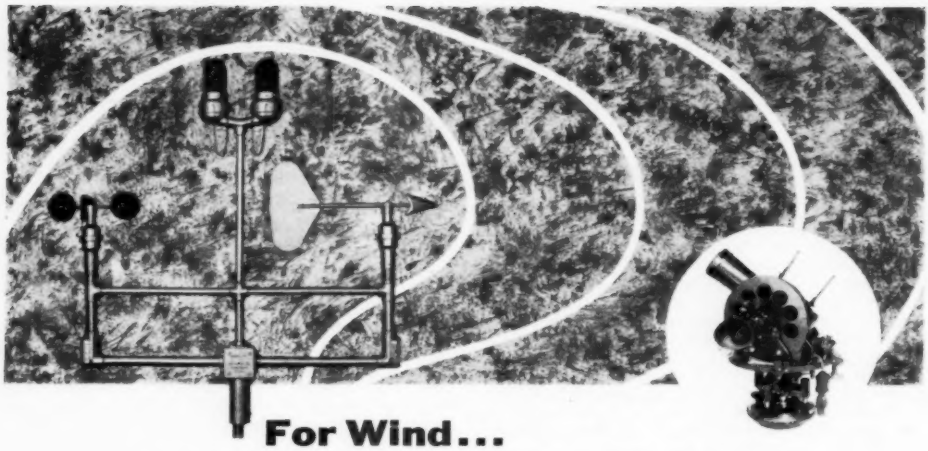

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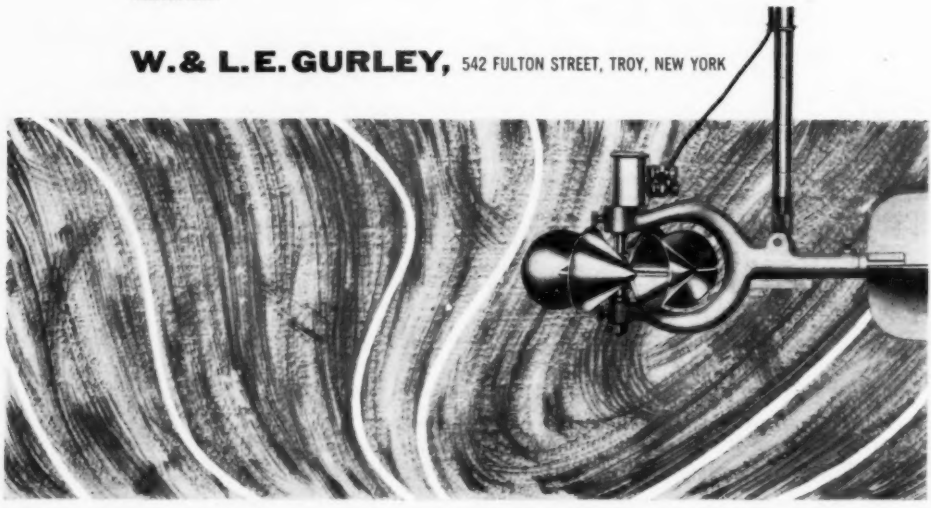

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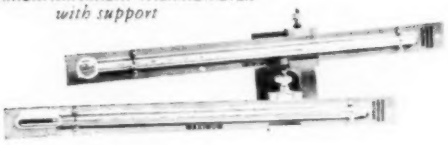

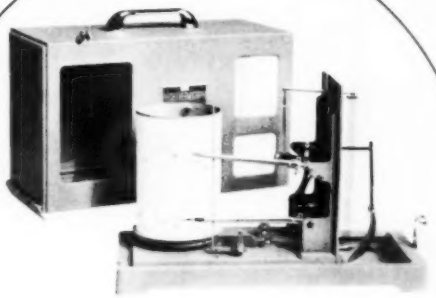

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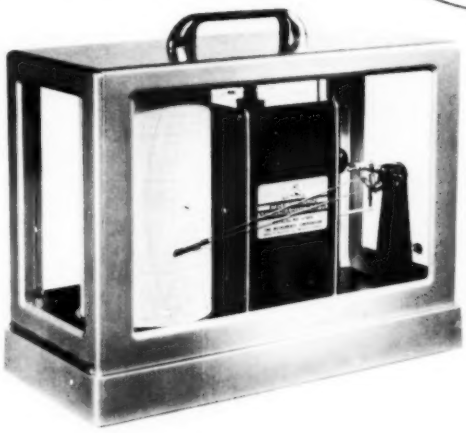

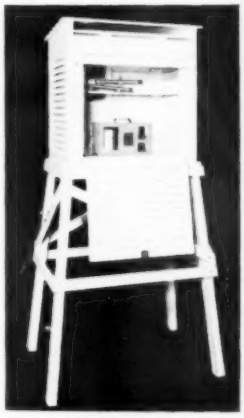

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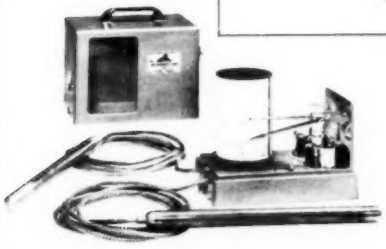

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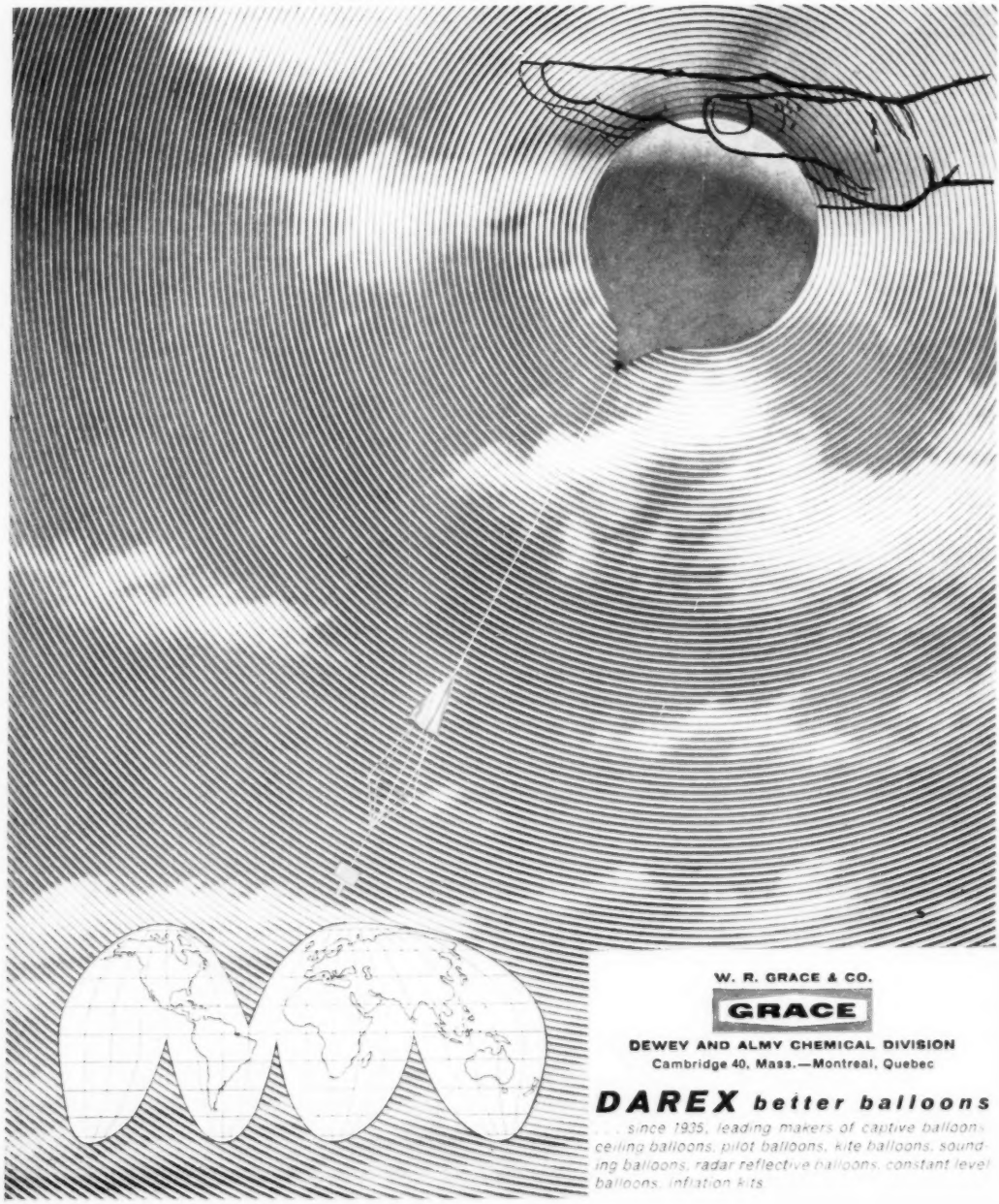

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